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# Systematic review of the human health effects of wind farms

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**Conflicts of interest**
The authors of this document have no financial or other conflicts of interest pertaining to wind farms or wind turbines.

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**Minor amendments published in February 2015**
The following amendments to the contents of this report were published in February 2015:

- Addition of a footnote in Table 27 and in Appendix B, indicating that the apparent error in the data presented in the table was directly transcribed from the source material (page 98 and page 251).
- A minor change to the definition of the term Odds Ratio in the Glossary (page 187).
- Minor corrections to data in the evidence tables in Appendix B (page 230 and page 240). These changes had no impact on the presentation or interpretation of results in the body of the report.

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# EXECUTIVE SUMMARY

## Purpose

This independent review of the literature was commissioned by the National Health and Medical Research Council (NHMRC) to determine whether there is an association between exposure to wind farms and human health effects and, if so, whether this association is causal or might be explained by chance, bias or confounding.

Direct evidence of any health effects was obtained through a systematic literature review of all the available evidence on exposure to the physical emissions produced by wind turbines. The emissions investigated were: noise, shadow flicker and the electromagnetic radiation (EMR) produced by wind turbines.

A background literature review was also undertaken to establish whether there is basic biological evidence, or evidence from research into other circumstances of human exposure to the physical emissions that wind turbines produce, that makes it plausible that wind turbines cause adverse health effects.

## Review questions

The review questions developed by the NHMRC Wind Farms and Human Health Reference Group (the Reference Group) are given on pages 21–23. A *background review* summarises general knowledge about a topic and is not intended to be answered comprehensively. A *systematic review* provides a transparent means for gathering, synthesising and appraising the findings of studies on a particular topic or question. The aim is to minimise the bias associated with the findings of single studies or non-systematic reviews. A systematic review provides a scientific analysis of all of the highest quality evidence available on a topic.

## Method

A protocol was developed to guide the conduct of the reviews. It outlined the project scope, research questions, and for the systematic review questions it provided the criteria for selecting and critically appraising studies, templates for extracting data and methods for synthesising the results obtained from the evidence-base. The review methods differed depending on whether the question being addressed was a systematic or a background review question. The protocol incorporated suggestions from the Reference Group.

The protocol was closely followed in order to maintain transparency and, for the systematic review questions, to ensure that there was no bias in study selection, appraisal or interpretation. All of the evidence obtained was categorised and interpreted in the context of epidemiological guidelines developed by Austin Bradford Hill, and modified by Howick, Glasziou and Aronson (2009). These guidelines suggest complementing the available direct evidence of the impact of an exposure or intervention (such as wind turbines) on an

outcome (such as adverse health effects) with mechanistic and parallel evidence, in order to determine likely cause and effect (see Figure ES. 1 and Table 5, page 40). Mechanistic evidence consists of studies that investigate the alleged causal mechanism that connects the exposure to health outcomes. Parallel evidence consists of studies that investigate the effects of exposures that are similar to the exposure of interest. This evidence provides support for a causal hypothesis.

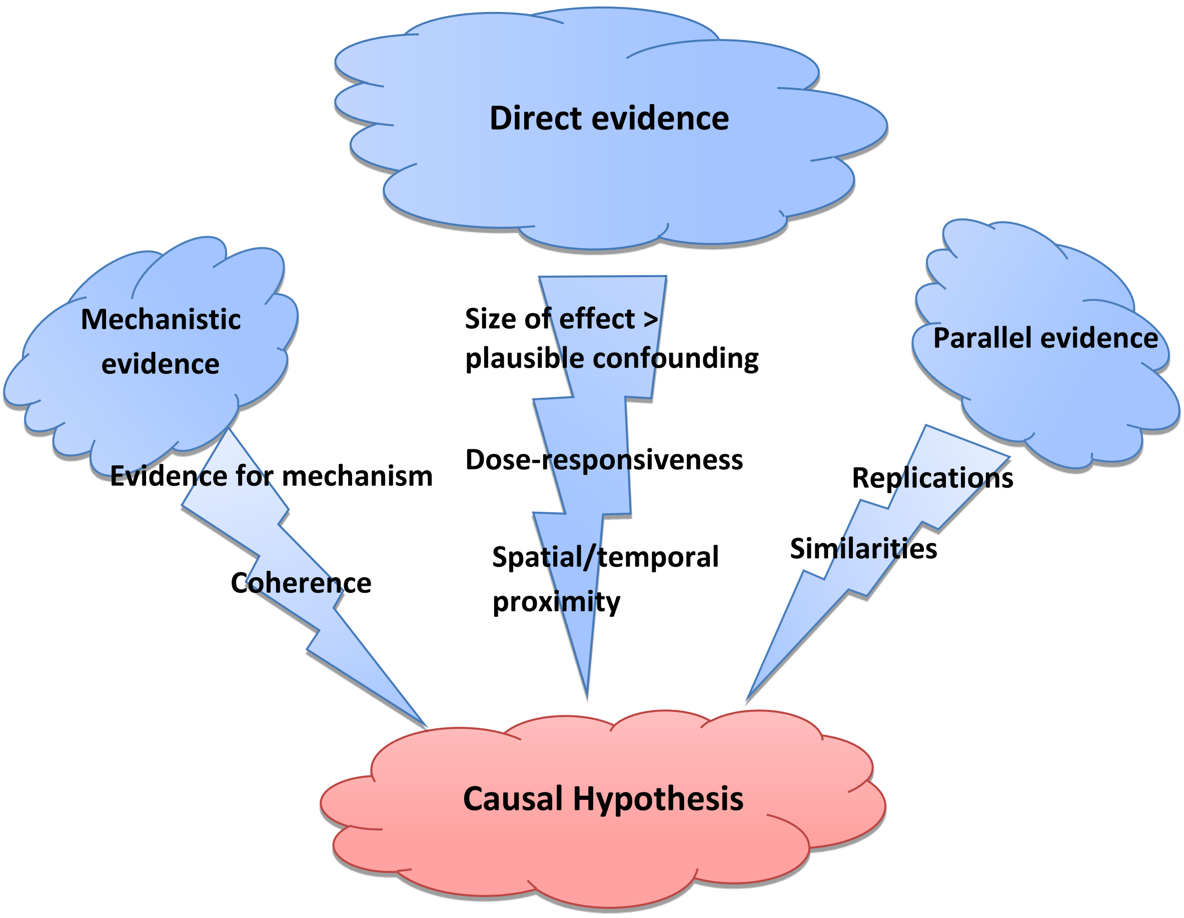


Figure ES. 1 Use of different types of evidence to support determination of causation (adapted from Howick, Glasziou and Aronson, 2009)

For this project the 'direct evidence' consisted of the evidence addressing the systematic literature review questions. The background review questions were concerned with the physiological mechanisms ('mechanistic evidence') by which noise, shadow flicker and EMR might produce adverse health effects, and whether any health effects have been observed from noise, shadow flicker and EMR produced by exposures other than wind turbines ('parallel evidence').

Within the conceptual framework offered by the modified Bradford Hill Guidelines, the direct evidence was assessed using an adaptation of the NHMRC FORM system for grading evidence (Hillier et al. 2011; NHMRC 2008). Studies were appraised in terms of their methodological rigour (level of evidence and likelihood of bias and confounding);

consistency of results; magnitude and precision of the estimates of human health effects; and generalisability and applicability of the findings to the Australian context. The findings from the mechanistic and parallel evidence were considered as 'Other Factors' that might upgrade or downgrade an evidence rating. Summary ratings were provided on a scale from A to D—an 'A' rating indicates that there is good support for an association between wind turbine emissions and human health effects, while a 'D' rating indicates poor support (Box 2, page 39).

## Results

A comprehensive search of the peer-reviewed (black) and grey[1] literature was conducted and identified 2850 potentially relevant references. The NHMRC also provided 506 documents obtained from public submissions or from other sources. However, only 11 articles—reporting on 7 cross-sectional studies that investigated associations between wind turbines and health—met pre-specified eligibility criteria (Box 1, page 33) to address the systematic review questions. The process of study selection for the systematic review questions is given in a PRISMA (Preferred Reporting Items for Systematic reviews and Meta-analyses) flowchart (Figure 1, page 43). These studies provided the direct evidence-base to evaluate the impact of wind turbines on human health.

The studies were conducted in Sweden (SWE-00 and SWE-05), The Netherlands (NL-07), Australia (Morris 2012), New Zealand (Shepherd et al. 2011), Canada (Krogh et al. 2011) and the USA (Nissenbaum, Aramini & Hanning 2012). As there were several publications and re-analyses of data in the Swedish and Dutch studies, an evidence map has been provided in Table 6, page 44. All of the studies were level IV aetiological (causal) evidence[2], with a high risk of bias due to sample selection and lack of masking in some studies. There was a risk of outcome misclassification in all studies as the physical adverse health outcomes reported by study participants were not objectively verified (e.g. through the use of medical case notes). Age and gender were usually adjusted for in the analyses, but other possibly confounding factors were not consistently controlled. It is a significant limitation of the available evidence that it was not known whether any of the observed health effects in residents were present or occurring at a different intensity prior to wind turbine exposure (ie demonstrating appropriate temporal proximity).

### Noise

Noise produced by wind turbines was discussed in all seven studies but infrasound and low-frequency noise (ILFN) were not specifically measured or discussed. One study (SWE-00)

[1] Definition is in the Glossary (source: <http://www.greynet.org/greynethome/aboutgreynet.html>).

[2] See

Table 4.

reported an association between estimated wind turbine sound pressure level (SPL) and self-reported tinnitus, and another study (SWE-05) reported a trend between SPL and self-reported diabetes. However, these findings were not replicated in the two other studies that assessed the same outcomes. It is possible that these isolated findings could have been due to differences in the distribution of possible confounders between exposure groups, or due to chance. None of the other physical health effects were found to be associated with estimated wind turbine SPL or distance from a wind turbine. Thus, associations of self-reported health effects with estimated noise exposure from wind turbines are inconsistent and possibly attributable to other factors.

The relationship between wind turbine proximity and quality of life was assessed by three studies. A New Zealand study (Shepherd et al. 2011) that attempted to mask respondents to the purpose of the survey and used a validated questionnaire reported that there was a significant association between distance from wind turbines and overall quality of life. Two other studies used author-formulated questions and did not mask the intent of the study, but found similar results. One Canadian study (Krogh et al. 2011) found that the majority of people reported that their quality of life had altered since living near a wind turbine, irrespective of their residential distance from a turbine (all lived within 2400 metres of a turbine). An American study undertaken in Maine (Nissenbaum, Aramini & Hanning 2012) reported a 74% difference in the number of residents wishing to move from the vicinity of a turbine (less than 1.4 km) when compared with residents living further away (over 3 km). The results of these studies were not adjusted for all plausible confounders, so it is unclear whether the association is due to wind turbine noise or other factors.

The results for possible associations between wind farm proximity and mental health measures were inconsistent. In the Maine study (Nissenbaum, Aramini & Hanning 2012) respondents who lived nearer wind farms reported statistically significantly poorer mental health, as measured by the SF-36 mental health component summary score, than those living further away. All participants in this study were aware that the study's purpose was to investigate the health effects of wind farms. In three of the four studies that provided contrary findings, the purpose of the research was masked from study participants. In these four studies there were no significant associations between estimated wind turbine noise exposure, or distance from a wind turbine, and levels of psychological distress, tension/stress, irritability, or self-reported depression and anxiety.

The association between estimated wind turbine noise and sleep was assessed by all seven included studies. Six of the seven studies reported poorer sleep—whether measured as higher rates of, or statistically significant differences in, sleep interruption or sleep quality—in those people with greater exposure to audible wind turbine noise[3] or living a shorter distance from wind turbines. Only the study from Maine (Nissenbaum, Aramini &

[3] Estimated A-weighted SPL

Hanning 2012) assessed reversibility, by asking respondents whether they had improved sleep when away from wind turbines. Half of those living less than 1.4 km from a wind turbine responded in the affirmative, compared with less than 6% of those who lived more than 3 km from a wind turbine.

No objective measures of sleep quality and sleep disturbance were used in these studies and the results were not adjusted for all plausible confounders e.g. annoyance and other factors that contribute to it. In the SWE-00, SWE-05 and NL-07 studies, the association between objective estimates of *sound pressure level* and sleep disturbance was not as strong as that between subjective assessments of wind turbine noise *annoyance* and sleep disturbance. In addition, some of the statistically significant differences in average sleep quality may not have been large enough to be meaningful.

Subjective levels of annoyance were consistently associated with wind turbine noise, both when outdoors and when indoors. Annoyance is not identified as a disease or health state, but it was still considered relevant to this systematic review because it is a universal negative human response to a condition or setting that may result in stress. Stress is a possible moderator or mediator of health outcomes. The five studies that assessed annoyance and noise exposure all reported statistically significant associations between annoyance and higher noise levels (estimated SPL) or residential proximity to a turbine. Rates of annoyance differed greatly between studies depending on level of estimated noise exposure, definition of annoyance (whether 'slightly annoyed' was classified as annoyed or not) and whether participants were masked to the study intent or not. The Dutch study (NL-07) found that 18% of respondents exposed to 35–45 dB(A) sound pressure were 'rather annoyed' or 'very annoyed' by wind turbine noise. A New Zealand study (Shepherd et al. 2011) reported that 59% of those living less than 2 km from a wind turbine were annoyed by the noise, while an Australian study (Morris 2012) reported that 56% of those living within 5 km of a wind turbine were disturbed by noise during the day.

The association between estimated noise level and annoyance was significantly affected by the visual attitude of the individual (i.e. whether they found wind farms beautiful, or ugly and unnatural) in the three studies that assessed this as a potential confounding factor (SWE-00, SWE-05, NL-07). Residents in the SWE-05 study with a negative attitude to the visual impact of wind farms on the landscape had over 14 times the odds of being annoyed compared with those people without a negative visual attitude. This was lower in the Dutch study (NL-07), ranging from 2.8 to 4.1 times the odds. Participants in SWE-00 reported that estimated SPL alone only accounted for 13% of the variance in the likelihood of annoyance, whereas estimated SPL plus visual attitude of the respondent accounted for 46% of the variance in annoyance. This means that factors other than the noise produced by wind turbines contribute to the annoyance experienced by survey respondents.

### *Systematic review evidence statement*

There is no consistent evidence that noise from wind turbines—whether estimated in models or using distance as a proxy—is associated with self-reported human health effects. Isolated associations may be due to confounding, bias or chance.

There is consistent evidence that noise from wind turbines—whether estimated in models or using distance as a proxy—is associated with annoyance, and reasonable consistency that it is associated with sleep disturbance and poorer sleep quality and quality of life. However, it is unclear whether the observed associations are due to wind turbine noise or plausible confounders. (D rating)

### *Mechanistic and parallel evidence*

Noise at high frequency lessens in intensity (loudness as measured by SPL) over much shorter distances than noise at lower frequencies. It does not pass easily through doors and windows—unlike ILFN, which can more easily pass through these obstacles. ILFN is, therefore, the exposure of most relevance at the range of distances typically observed between residential dwellings and commercial wind turbines. Hearing becomes gradually less sensitive as frequency decreases, so for humans to perceive infrasound and low frequency noise, the SPL needs to be high.

However, deriving a single SPL from wind turbines in the presence of background noise is difficult. The 2013 South Australian Environment Protection Authority study (Evans, Cooper & Lenchine 2013) measured infrasound at urban and rural locations and compared these with measurements taken at residences near two wind farms. Levels of background noise at residences near wind farms were also measured during organised shutdowns of the turbines. It was concluded that the level of infrasound at locations near wind farms was no greater than that experienced in other urban and rural environments. Further, the contribution of wind turbines to the measured infrasound levels taken at residences at a distance of approximately 1.5 km was insignificant in comparison with the background level of infrasound in the environment.

The available evidence addressing the background questions indicates that there are possible health effects from exposure to high audible noise levels, e.g. from road traffic (WHO 2011). However, as distance is closely related to estimated SPL, it is not expected that substantial audible noise exposures (>45 dB(A)) would be associated with modern wind turbines at distances of more than about 280 m (Ellenbogen et al. 2012), although this might vary by terrain, type of wind turbine and wind conditions. Sleep disturbance from noise exposure alone is not plausible at noise levels of 30 dB(A) and below, and has only modest effects at 40 db(A) and below (WHO 2011).

The ILFN produced in the available laboratory studies was frequently greater than (usually A-weighted) 80 dB and ranged between 40 and 144 dB. Under these conservative conditions, ILFN appeared to have inconsistent and inconclusive effects on intermediate physiological measures taken from study participants. Health outcomes were not studied. Physiological changes such as heart rate, cortisol level, respiratory rate and blood pressure were measured. The data suggest that low-frequency noise at high SPLs may elicit a temporary threshold shift in hearing (Alford et al. 1966; Mills et al. 1983) and may lead to statistically significant, albeit very small and inconsistent, changes in systolic and diastolic blood pressure, and pulse or heart rate. There were too few studies reporting on exactly the same intervention or outcomes to determine if the results were replicable, and where studies were similarly designed there were inconsistent findings with respect to whether or not ILFN influenced physiological measures.

## Shadow flicker

### *Direct evidence*

No studies of good quality were identified that linked shadow flicker with adverse health outcomes. One small cross-sectional study (Morris 2012) with a high risk of bias reported on the association between shadow flicker and annoyance. Annoyed individuals reported symptoms of headache and blurred vision. Those living within 5 km of a wind turbine were more likely to report noticing shadow flicker, and being annoyed by it, than those who lived between 5 and 10 km from a wind turbine. No data on the rate of adverse outcomes, other than annoyance, were reported from this study. No conclusions could therefore be drawn regarding the association between adverse health outcomes and shadow flicker produced by wind turbines.

### *Mechanistic and parallel evidence*

It is well recognised that shadow flicker exposure can affect health by inducing seizures in those prone to photosensitive epilepsy. This very rare condition can be induced by repetitive flashing lights and static repetitive geometric patterns, with the flicker inducing transient abnormal synchronised activity of brain cells and affecting consciousness, bodily movements and/or sensation. The timing, intensity and location of exposure to the shadow flicker produced by wind turbines is dependent on turbine size and shape, blade diameter, height of the sun and the blade direction relative to the observer. These variables are affected by wind direction and the time of day, time of year, and geographical location that the observation takes place. The Environment Protection and Heritage Council of Australia (EPHC 2010) estimate that the probability of a conventional horizontal-axis wind turbine causing an epileptic seizure due to shadow flicker is less than 1 in 10 million in the general population.

The sparse laboratory evidence available investigating the association between shadow flicker and health outcomes was of uncertain applicability to the shadow flicker conditions produced by wind turbines. One study found no difference in stress-related outcomes between groups exposed and not exposed to shadow flicker but it could not be determined whether the flicker frequencies investigated were similar to those produced by wind turbines (Pohl, Faul & Mausfeld 1999). The other study found photoparoxysmal responses to a range of frequencies relevant to the flicker produced by wind turbines (>3 Hz) but the flicker exposure involved coloured light, rather than shadow, and all of the participants were photosensitive individuals (Shirakawa et al. 2001).

## Electromagnetic radiation

### *Direct evidence*

No studies were identified that specifically investigated an association between EMR (either extremely low-frequency (ELF) or other EMR frequencies) near wind farms and human health effects. Unless specified otherwise, reference to EMR in this section should be taken to be a reference the ELF EMR that is associated with alternating electrical currents.

### *Mechanistic and parallel evidence*

Mechanistic studies indicate that the effects of external exposure to EMR on the human body and its cells depend mainly on the EMR frequency and strength (WHO 2002). It is known that the strength of an alternating electromagnetic field rapidly decreases as distance from the source increases (WHO 2012b). ELF EMR can produce eddy currents in human tissue. Since biochemical mechanisms and nerve transmission utilise electric impulses, exposure to ELF EMR could interfere with electrical currents that are vital to normal bodily function if the person is in close proximity to the source of the EMR.

In wind farms EMR is emitted from grid connection lines, underground collector network cabling, electrical transformers and turbine generators. However, there are scant data (one industry example only (Windrush Energy 2004)) on the magnitude and/or level (quantity) of EMR present in the vicinity of wind turbines. The available industry data suggests that the EMR levels near wind farms are likely to be within the range of EMR emitted by household appliances.

The applicability of the available parallel evidence on EMR to the wind farm context is uncertain. Concerns regarding the safety of EMR were raised with the publication of an early study reporting an association between the risk of childhood leukaemia and the degree of EMR exposure from electricity transmission lines (Wertheimer & Leeper 1979). Research has also been conducted on possible associations between occupational EMR and cancer or cardiovascular, neurological/psychological and reproductive diseases. However, apart from the study of childhood leukaemia, results from these EMR studies are characterised by a high degree of heterogeneity and are inconclusive (Ahlbom et al. 2001).

### Other emissions

No other type of physical emission from wind farms that might cause adverse health effects was identified in the literature.

## Conclusion

### Direct evidence

In summary, the systematic review indicated that there was no consistent evidence that noise from wind turbines, whether estimated in models or using distance as a proxy, is associated with self-reported human health effects. The quality and quantity of the available evidence was limited.

Proximity to wind turbines or estimated SPL was associated with annoyance, and often associated with sleep disturbance and poorer quality of life. However, it cannot be ruled out that bias or confounding is an explanation for these associations.

Shadow flicker produced by wind turbines was found to be associated with annoyance in one small study, but health effects were not measured. There were no studies identified that investigated the impact on health of the EMR produced by wind turbines.

### Mechanistic and parallel evidence

The information addressing the background review questions on possible mechanisms, and parallel circumstances, by which wind turbine emissions could impact on health was not persuasive. Although there were possible mechanisms by which shadow flicker and EMR could cause adverse health effects, the applicability of the available laboratory evidence to the wind turbine context could not be demonstrated.

Mid-to high frequency noise from wind turbines is unlikely to be significant at normal residential distances from wind turbines. ILFN from wind turbines is possible but difficult to isolate over the levels of background infrasound that are commonly present in the environment (e.g. wind noise in rural environments). The mechanism by which ILFN could cause adverse health effects is not clear and the available parallel laboratory evidence was inconclusive with regard to the effect on intermediate physiological outcomes as findings were inconsistent within and between studies.

### Evidence for causation

To evaluate the strength of the evidence for a cause-and-effect relationship between wind turbine emissions (noise, shadow flicker and EMR) and adverse human health and health-related effects, the totality of the evidence was assessed in terms of the conceptual framework offered by the modified Bradford Hill Guidelines (Table 5, page 40).

The reported effects in the studies did occur near wind turbines (spatial proximity). However, with the exception of annoyance, sleep quality or sleep disturbance and quality of life—the latter of which are possibly related to health—there was no consistent association between adverse health effects and estimated noise from wind turbines. Any isolated associations that were observed could have been due to plausible confounding or a spurious result from undertaking multiple statistical tests. Whether any of the reported effects followed the onset of exposure to wind turbines (temporal proximity) could not be ascertained because of the cross-sectional nature of the available studies. From these data, no dose-response relationship was observed between estimated sound pressure level or distance from a wind turbine and the direct health effects examined.

A dose-response relationship was apparent between wind turbine proximity and the possibly health related effects of sleep disturbance, poor sleep quality and quality of life; these effects were less common as the estimated SPL reduced or distance from the wind turbines increased. However, there is a possibility that the associations with sleep quality, sleep disturbance and quality of life are confounded by annoyance and other factors that determine it. Evidence of reversibility was present in one small study. Participants in this study recalled less sleep disturbance when they were away from wind turbines. The participants knew that the purpose of the study was to investigate wind turbine noise.

Possible mechanisms by which wind turbines could harm human health—and which are coherent with existing scientific theory—were plausible for shadow flicker and ELF EMR exposure but were of uncertain applicability to the wind turbine context. A mechanism by which ILFN could harm human health could not be determined. There was no consistent association observed between ILFN and intermediate physiologic effects (e.g. blood pressure) in the laboratory setting. Health outcomes were not measured.

The quality and quantity of evidence available to address the questions posed in this review was limited. The evidence considered does not support the conclusion that wind turbines have direct adverse effects on human health, as the criteria for causation have not been fulfilled. Indirect effects of wind farms on human health through sleep disturbance, reduced sleep quality, quality of life and perhaps annoyance are possible. Bias and confounding could, however, be possible explanations for the reported associations upon which this conclusion is based.

# INTRODUCTION

Adelaide Health Technology Assessment (AHTA) was commissioned by the National Health and Medical Research Council (NHMRC) to conduct a review of the health effects of wind turbines on humans.

## Objective of the review

The objective of the review was to determine whether there is an association between exposure to wind farms and human health effects and, if so, whether this association is causal or might be explained by chance, bias or confounding.

## Rationale for the review

Wind turbines generate electricity using the wind and are promoted as a viable and sustainable alternative to traditional, non-renewable forms of energy production.

The presence of wind turbines in the environment is not without controversy, and many claims and counter claims of the negative health effects of turbines have been made. The issue is highly emotive, not only because of the controversy regarding negative effects on human health, but also because there are financial implications for land owners and power companies. These controversies have impacted on wind farm installation. For example, in South Australia, plans for two potential wind farms were either withdrawn by the company building them (as reported in *The Advertiser* on 23 August 2012) or refused planning permission by the local council (as reported on <www.abc.net.au/news> on 14 August 2012).

In 2010 the NHMRC produced a rapid review of the evidence on the health effects of wind turbines on humans (National Health and Medical Research Council 2010). The review investigated the potential health impact of the following turbine-related exposures:

- infrasound/noise
- electromagnetic interference
- shadow flicker
- blade glint

The review found 'no direct pathological effects from wind farms' while suggesting that 'if planning guidelines are followed and communities are consulted with in a meaningful way, resistance to wind farms is likely to be reduced and annoyance and related health effects avoided' (National Health and Medical Research Council 2010). The NHMRC's Public Statement, *Wind turbines and health*, based on this review, indicated that, while there was currently no evidence linking the identified turbine-related exposures with adverse health effects, the evidence was limited (National Health and Medical Research Council 2010a).

The Public Statement recommended that relevant authorities take a precautionary approach and continue to monitor relevant research. It was suggested that compliance with standards relating to wind turbine design, manufacture and site evaluation would minimise any potential impacts of wind turbines on surrounding areas.

In 2011 a Senate Inquiry, 'The Social and Economic Impact of Rural Wind Farms', was conducted. The inquiry received more than 1000 submissions and held public hearings in four cities. It recommended a precautionary approach to noise standards, including conducting epidemiological and laboratory studies of the possible effects of wind farms on human health, as well as continuing the NHMRC review of research. The Australian Government accepted four of the seven recommendations of the inquiry, including supporting the recommendation that the NHMRC should continue the review of current research in the field, with regular publication of findings (Australian Government 2012).

In June 2011 the NHMRC held a forum on the issues related to the possible health effects of wind turbines[4], leading to five major conclusions:

1. There is insufficient published, peer-reviewed, high-quality scientific evidence concerning infrasound and its effect on human health.
2. Research on infrasound and audible noise needs to include variables such as proximity to turbines, wind levels, topography and structure of residential housing.
3. Social and economic factors need to be considered when analysing the impact of wind farms on human health.
4. A thorough review should be conducted that evaluates the literature against defined levels of evidence, and highlights limitations in the available literature.
5. The review should consider all aspects of noise, including infrasound (less than 20 Hz) and audible noise (greater than 20 Hz).

Although there are many narrative reviews on the topic of wind farms (often produced by environmental protection or health authorities), none to date have addressed the topic using a formal evidence-based systematic literature review. This type of review requires a protocol or methodology to be developed prior to the review being undertaken, to provide transparency and thus potential replication of the review method, maintenance of impartiality and rigour in study selection, and formal standardised critical appraisal and synthesis of study results. A review of this type has been commissioned by the NHMRC in response to point 4 above, and is presented in this document. The NHMRC Wind Farms and Human Health Reference Group (the Reference Group) was established to oversee the proposed review. Depending on the outcomes of the review, the Reference Group will

[4] <http://www.nhmrc.gov.au/media/events/2011/wind-farms-and-human-health-scientific-forum-7-june-2011>

consider whether the NHMRC's 2010 Public Statement should be revised on the basis of the more robust and comprehensive evidence that this systematic review will provide.

## Review questions

The Reference Group posed several questions to be answered by the review, and these were categorised as either background review questions or systematic review questions. A background review question seeks general knowledge about a topic and is not intended to be answered comprehensively. A systematic review question seeks a transparent means for gathering, synthesising and appraising the findings of studies on a particular topic. The aim is to minimise the bias associated with the findings of single studies or non-systematic reviews. It provides a scientific analysis of all of the highest quality evidence available on a topic.

### Background review questions

A comprehensive background narrative was requested to answer the following questions:

BQ1. What are wind turbines and wind farms?

BQ2. By what specific physical emissions might wind turbines cause adverse health effects?

BQ3. For each such emission, what is the level of exposure from a wind turbine and how does it vary by distance and characteristics of the terrain separating a wind turbine from potentially exposed people?

BQ4. Is there basic biological evidence, or evidence from research into other circumstances of human exposure to physical emissions that wind turbines produce, that make it plausible that wind turbines cause adverse health effects?

BQ5. Is there any direct research evidence that exposure to wind turbines is associated with adverse health effects?

BQ6. If there is evidence that exposure to wind turbines is associated with adverse health effects:

a. Is there evidence that there are confounding factors or effect modifiers that might explain the association of wind turbines with adverse health effects? Such as but not necessarily limited to:
    i. visibility of turbines
    ii. financial gain from the siting of turbines
    iii. community participation in decision making on the siting of turbines
    iv. age and design of turbines?

## Systematic review questions

The formal evidence-based questions were as follows:

### *Distance*

SQ1. Is there any reliable evidence of an association between distance from wind turbines and adverse health effects? If so:

a. How strong is this association?
b. How does the strength of this association relate to distance from wind turbines?
c. Might this association be explained by:
    i. chance?[5]
    ii. bias? or
    iii. confounding?

### *Audible noise*

SQ2. Is there any reliable evidence of an association between audible noise (greater than 20 Hz) from wind turbines and adverse health effects? If so:

a. How strong is this association?
b. How does the strength of this association relate to level of exposure to audible noise from wind turbines?
c. Might this association be explained by:
    i. chance?
    ii. bias? or
    iii. confounding?

### *Infrasound and low-frequency noise*

SQ3. Is there any reliable evidence of an association between infrasound and low-frequency noise (less than 20 Hz) from wind turbines and adverse health effects? If so:

a. How strong is this association?
b. How does the strength of this association relate to level of exposure to infrasound/inaudible noise from wind turbines?
c. Might this association be explained by:
    i. chance?
    ii. bias? or
    iii. confounding?

[5] For definitions of *chance*, *bias* and *confounding,* please see Glossary and Methods sections.

### *Shadow flicker*

SQ4. Is there any reliable evidence of an association between shadow flicker (photosensitivity[6] greater than 3 Hz) from wind turbines and adverse health effects? If so:

a. How strong is this association?
b. How does the strength of this association relate to level of exposure to shadow flicker from wind turbines?
c. Might this association be explained by:
    i. chance?
    ii. bias? or
    iii. confounding?

### *Electromagnetic radiation*

SQ5. Is there any reliable evidence of an association between electromagnetic radiation from wind turbines and adverse health effects? If so:

a. How strong is this association?
b. How does the strength of this association relate to level of exposure to electromagnetic radiation from wind turbines?
c. Might this association be explained by:
    i. chance?
    ii. bias? or
    iii. confounding?

Areas that were out of scope for the review included:

- potential effects on human health from wind farm manufacturing and monitoring, such as occupational health and safety issues
- planning, development and monitoring activities related to wind farms
- the potential health effects of 'ice throw' and 'accident secondary to mechanical failure'.

[6] Photosensitivity is an abnormal sensitivity to light stimuli, usually detected with electroencephalography (EEG) as a paroxysmal reaction to intermittent photic stimulation (IPS). The EEG response elicited by IPS or other visual stimuli of daily life is called photoparoxysmal response (PPR) (Verrotti et al. 2005).

# WIND TURBINES AND WIND FARMS

## *BQ1. WHAT ARE WIND TURBINES AND WIND FARMS?*

Wind occurs in response to the differential heating of parts of the earth and the earth's rotation. A wind turbine uses wind to produce electricity. There are two main types of wind turbine: the horizontal axis wind turbine (HAWT)[7] and the vertical axis wind turbine (VAWT). HAWTs are more common because they are considered to be more efficient (Ali et al. 2011).

A group of wind turbines is known as a wind farm. A large wind farm may consist of several hundred individual wind turbines, cover a large geographical area and be located offshore or on land.

## Wind farms in Australia

There has been a strong focus on wind power as an alternative to more traditional forms of energy production in Australia since the *Renewable Energy Act 2000* was legislated[8]. Wind power is considered to be a clean renewable energy source with no carbon dioxide emissions.

The first wind farm in Australia was constructed at Salmon Beach, Esperance (commissioned in March 1987), and consisted of six 60 kilowatt (kW) turbines (Ali et al. 2011). Towards the end of 2011 Australia had over 1 gigawatt (GW) of wind power installed (Table 1). By comparison, Europe had 57 GW operational in 2009 (European Wind Energy Association 2009).

The development of modern wind turbines has been an evolutionary design process, with performance optimisation occurring at many levels. Over the past 20 years wind turbines have evolved to minimise noise and to enable better exploitation of wind energy (Ellenbogen et al. 2012; Jakobsen 2005; Knopper & Ollson 2011). The majority of current large-scale wind turbines have a cylindrical tower structure (allowing internal access) and highly contoured turbine blades. Table 1 provides an overview of operational wind farms over 1 megawatt (MW) capacity in Australia until 2011 (Barry & Yeo 2011).

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[7] The rotor plane includes the blades, and the hub turns so that the wind is perpendicular to the plane.

[8] <http://www.comlaw.gov.au/Details/C2012C00858>

Table 1 Wind farms operating in Australia by commissioning date

| Commissioned | Project name | State | Developer | Size (MW) |
|---|---|---|---|---|
| 1998 | Crookwell | NSW | Eraring Energy | 4.8 |
| 2000 | Blayney | NSW | Eraring Energy | 9.9 |
| 2000 | Windy Hill | QLD | Stanwell | 12.0 |
| 2001 | Hampton | NSW | Wind Corporation Australia | 1.3 |
| 2003 | Starfish Hill | SA | Transfield Services | 34.5 |
| 2004 | Canunda | SA | International Power/Wind Prospect | 46.0 |
| 2004 | Lake Bonney Stage 1 | SA | Infigen Energy | 80.5 |
| 2005 | Cathedral Rocks | SA | Hydro Tasmania & Acciona Energy | 66.0 |
| 2005 | Mount Millar (Yabmana) | SA | Tarong Energy, Transfield Services | 70.0 |
| 2008 | Hallett 1 (Brown Hill) | SA | AGL | 94.5 |
| 2008 | Lake Bonney Stage 2 | SA | Infigen Energy | 159.0 |
| 2008 | Snowtown | SA | TrustPower | 98.7 |
| 2009 | Capital Wind Farm | NSW | Infigen Energy | 140.7 |
| 2009 | Cullerin Range | NSW | Origin Energy | 30.0 |
| 2009 | Hallett 2 (Hallett Hill) | SA | AGL | 71.4 |
| 2009 | Lake Bonney Stage 3 | SA | Infigen Energy | 39.0 |
| 2010 | Clements Gap | SA | Pacific Hydro | 56.7 |
| 2010 | Waterloo | SA | Roaring 40s | 111.0 |
| 2011 | Hallett 4 (North Brown Hill) | SA | AGL | 132.3 |

Source: Barry and Yeo (2011)

In Australia the state and territory governments oversee the placement of wind turbines. However, where there is a perceived threat to endangered or migratory animals, major wetlands or heritage sites, the federal government has regulatory powers (Haugen 2011).

## How power is produced by wind turbines

Wind power is produced from the kinetic energy of air movement. Not all the available power in the wind can be captured by a wind turbine. The power available to a wind turbine can be estimated from the cube of the wind speed and the square of the rotor radius; that is, wind power is proportional to the third power of the wind velocity (Raymond 2012). To estimate the wind power captured by a wind turbine, both input and output wind velocities are crucial elements for consideration. Total wind power is captured only if the wind velocity is reduced to zero. However, in the practical setting, this is impossible to achieve as the captured air must also exit the turbine (Ellenbogen et al. 2012). Using Betz's law, it is estimated in the literature that the maximum achievable wind power capture by a wind turbine is 59% of the total theoretical efficiency (Grogg 2005). Modern turbines have very large rotors to maximise the power obtained, noting that the number of rotor blades and tip speed also influence performance (i.e. solidity); however, trade-offs exist in terms of weight, cost and noise (Ellenbogen et al. 2012). Loss of energy from rotor blade friction and drag, gearbox losses, and generator and converter losses all contribute to reducing the power delivered by a wind turbine (Ellenbogen et al., 2012; Grogg 2005; Harding, Harding & Wilkins 2008; Hawkins 2012; Knopper & Ollson 2011).

# REVIEW METHODOLOGY

A protocol was developed to guide the conduct of the project. It outlined the scope of the review, research questions, and for the systematic review questions it provided the criteria for selecting and critically appraising studies, templates for extracting data and methods for synthesising the results obtained from the evidence-base. The protocol was developed in conjunction with the Reference Group.

The protocol was closely followed throughout the conduct of the review, and the methods are described below. The review methods differed depending on whether the question being addressed was a systematic review question or a background review question.

## Methodology to address background review questions

A broad literature search was conducted to inform Background Questions 1–3, and 6. This included basic information needed to understand the issues under investigation, along with information from peer-reviewed literature (i.e. narrative expert reviews and primary research reports) and technical reports and analyses produced by expert panels and environmental health agencies. It is important to note that this part of the review was not required to be performed systematically; thus, systematic searching and selection of studies was not undertaken. At the Reference Group's request, the aim was to provide a broad outline of the pertinent issues and to describe the circumstances under which wind farms operate and may impact on human health. The search was limited to information published after the establishment of the first commercial wind farm in 1981, and information was only included if it was relevant to humans and published in English. The search for relevant literature also included pearling[9] of the reference lists of relevant reviews and reports, and snowballing[10] to identify related pertinent literature. Background Question 5 was effectively answered by all the systematic review questions, and so it is not addressed or labelled separately in the Results section of this document.

Background Question 4[11] required a different approach. Although this question was not answered using a systematic literature review, as with the other background questions, a more systematic approach was applied given that it was about biological plausibility, and so could be material to the strength of conclusions arrived at using the proposed theoretical causality framework (page 40).

The literature search for Background Question 4 did not have chronological limits, but was limited to studies of humans that were published in English. To facilitate the identification of

[9] Definition is in the Glossary.

[10] Definition is in the Glossary.

[11] BQ4: Is there basic biological evidence, or evidence from research into other circumstances of human exposure to noise emissions, that make it plausible that wind turbines cause adverse health effects?

high-level evidence, only the peer-reviewed literature was eligible. Studies classified by the NHMRC evidence hierarchy (Merlin, Weston & Tooher 2009) (Table 4) as level I and II for aetiology studies were considered for this question; however, there was provision to look at lower level evidence if there was limited high-level evidence available. Given the restriction by study design and the exploratory nature of this background question, no formal quality appraisal was conducted. The search strategy for Background Question 4 is described in Table 2. If additional specific physical emissions related to wind turbines had been identified in Background Question 2, that were not covered by the search terms outlined in Table 2 (e.g. vibrations through the ground), additional searches would have been performed to assess these separately; however, this situation did not arise. Literature on each *a priori* identified exposure (audible sound, inaudible or low-frequency sound, shadow flicker and electromagnetic radiation) attributed to wind turbines was identified, and only studies that fulfilled the eligibility criteria were considered.

Table 2 Search strategy and criteria for selecting evidence to inform Background Question 4

| Question: are there human health effects associated with: | Search terms for PubMed and Embase | Eligibility criteria |
|---|---|---|
| **Audible noise (greater than or equal to 20 Hz)**<br>**Infrasound (less than 20 Hz)** | 1) PubMed: "Noise/adverse effects"[Mesh] AND (Cohort studies[Mesh] OR cohort analysis)<br>2) PubMed: "Noise/adverse effects"[Mesh] AND systematic[sb]<br>3) Embase: 'noise injury'/exp AND<br>• 'human'/de AND ('article'/it OR 'review'/it) AND [english]/lim<br>• ('clinical trial'/de OR 'cohort analysis'/de OR 'controlled clinical trial'/de OR 'controlled study'/de OR 'longitudinal study'/de OR 'prospective study'/de OR 'randomized controlled trial'/de) AND [humans]/lim AND [english]/lim | Level I evidence: systematic reviews of level II evidence; level II evidence: prospective cohort studies[a]<br><br>Limited to studies of humans and those in English<br><br>No chronological limits |
| **Shadow flicker (photosensitivity greater than 3 Hz)** | 1) PubMed: (“shadow flicker” OR photic stimulation/adverse effects OR seizures/etiology OR epilepsy reflex/etiology) AND (Cohort studies[Mesh] OR cohort analysis)<br>2) PubMed: (“shadow flicker” OR photic stimulation/adverse effects OR seizures/etiology OR epilepsy | |

| | | |
|---|---|---|
| | reflex/etiology) AND systematic[sb]<br>3) Embase: ('shadow flicker' OR 'shadow' OR 'flicker') AND ('photic stimulation'/exp OR 'seizure'/exp OR 'seizure susceptibility'/exp OR 'adverse effects' OR annoyance) AND<br>• 'human'/de AND ('article'/it OR 'review'/it) AND [english]/lim<br>• ('clinical trial'/de OR 'cohort analysis'/de OR 'controlled clinical trial'/de OR 'controlled study'/de OR 'longitudinal study'/de OR 'prospective study'/de OR 'randomized controlled trial'/de) AND [humans]/lim AND [english]/lim | |
| **Electromagnetic radiation** | 1) PubMed: ("Electromagnetic fields/adverse effects"[Mesh] AND "electric power supplies/adverse effects"[Mesh]) AND (Cohort studies[Mesh] OR cohort analysis)<br>2) PubMed: ("Electromagnetic fields/adverse effects"[Mesh] AND "electric power supplies/adverse effects"[Mesh]) AND systematic[sb]<br>3) Embase: ('Electromagnetic field'/exp AND 'power supply'/exp) AND<br>• 'human'/de AND ('article'/it OR 'review'/it)) AND [english]/lim<br>• ('clinical trial'/de OR 'cohort analysis'/de OR 'controlled clinical trial'/de OR 'controlled study'/de OR 'longitudinal study'/de OR 'prospective study'/de OR 'randomized controlled trial'/de) AND [humans]/lim AND [english]/lim | |

[a] Due to limited level I or level II evidence being identified, the review included studies of lower level evidence (level III-1 and III-2). As no case-control studies (level III-3) were identified, these were not included. See Table 30, Table 33 and Table 38 for study details.

Background Question 6 and the systematic review questions had a similar focus on the effect of potential confounding factors on observed associations between wind turbines and adverse health effects. Where there was overlap in the questions, this was labelled accordingly in the Results section of the report. When there was no element of overlap between the systematic review questions and Background Question 6, the questions were labelled separately in the Results section of the report.

## Methodology to address systematic review questions

### Literature search strategy

The search strategy for the systematic review investigated both the peer-reviewed (black) literature and grey literature[12]. Grey literature sources often include a combination of both black and grey literature, and black literature often includes grey literature that has subsequently been published, so overlap in results between the two search strategies was expected.

The search canvassed the following databases: PubMed, Embase.com, The Cochrane Library, Psycinfo and Web of Science (the latter refined by health-related web of science categories, e.g. public/environmental/occupational health). Relevant papers had their reference lists pearled for papers that may have been missed in the searches. The search was limited to papers that were published after the first commercial wind farm was established in 1981, involved humans and were published in English. Searches of the peer-reviewed literature were not restricted according to study design.

Scoping searches revealed a paucity of peer-reviewed studies; therefore, the search terms were kept broad to ensure that no studies were missed. It was considered likely that the available literature would consist primarily of observational studies[13]. The search strategy for the peer-reviewed literature is described in Table 3, using the example of the Medical Subject Headings (MeSH) appropriate for PubMed. Equivalent indexing terms were used for other databases.

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[12] Definition is in the Glossary (source: http://www.greynet.org/greynethome/aboutgreynet.html).

[13] It was not expected that experimental evidence (e.g. from randomised controlled trials) would be available to inform the systematic review questions.

### Table 3 Search terms to identify evidence to inform the systematic review questions

| **Peer-reviewed literature search terms (PubMed example)** |
|---|
| (wind[all fields] AND (turbine*[all fields] OR farm[all fields] OR farms[all fields] OR tower*[all fields] OR energy[all fields] OR technology[all fields] OR energy generating resources[MeSH] OR electric power supplies[MeSH])) OR wind turbine syndrome[all fields] OR Wind power[all fields]<br><br>Limits: 1981 – 10/2012; English language; human studies |

Scoping searches indicated that there was a considerable amount of grey literature available on this topic. The grey literature search included use of Google Scholar, databases of conference proceedings, known grey literature sources, and selected government and scientific association websites (see APPENDIX A). The search strategy also included pearling of relevant reviews and reports and snowballing techniques to locate articles and reports in obscure locations.

In addition to literature obtained through these methods, NHMRC had called for public submissions of relevant non-peer-reviewed literature to inform the systematic review. These submissions were only eligible for consideration if they were:

- publicly available from a readily accessible source;
- described the systematic collection and analysis of data; and
- reported analytical results that were relevant to wind farms and human health.

Literature, whether peer reviewed or not, was not eligible for consideration if:

- the observations lacked organisation or analysis;
- it was an expression of opinion and was not based on the results of research; or
- it was based solely on haphazardly collected or unstructured personal testimony.

Public submissions to the NHMRC that met these screening criteria were then assessed as to whether they addressed the systematic review questions. This was determined using selection criteria pre-specified in the protocol for the review (see below and Box 1).

## Study selection criteria

Studies eligible for inclusion in the systematic review had one of the designs described in the NHMRC evidence hierarchy for aetiology questions (Table 4), including systematic reviews of each of the study designs. These designs were eligible because they allow the impact of an exposure on health outcomes to be measured. Level IV studies were included if they were cross-sectional studies that provided results for respondents who were exposed to different sound pressure levels (SPLs) or who were living at different distances from wind turbines; that is, subgroup analysis according to level of exposure (for which distance from

wind turbines is a surrogate) was allowed. Studies without a within-group or between-group comparison (i.e. case series[14]) were excluded on the advice of the Reference Group.
The Reference Group was aware of literature stating that case reports should be considered when assessing the health effects of wind turbines (Phillips 2011). However, individual case reports and collations of case reports (e.g. where all participants were selected because they had a health problem they attributed to wind turbines) were excluded from this systematic review because they provide no *objective* information by which reported health problems could be related to presence of, or amount of exposure to, wind turbines. Case reports and case series can be useful in generating hypotheses about the health effects of particular exposures, but they are not useful for testing these hypotheses except where a causal connection between exposure and health outcome is self-evident from the report (as, e.g., in the case of the 'mother's kiss'; Howick, Glasziou & Aronson 2009).

Examples of literature identified as opinion pieces, editorials or other papers without a clear study design and description of methods and results were not included. No limitations were placed on study outcomes—any study that had any type of adverse health effect as an outcome was eligible for inclusion in the review. These criteria were delineated using the PECOT structure[15], which is appropriate to the assessment of epidemiological studies that would be addressing each of the systematic review questions (see Box 1).

## Exclusion criteria

Studies were excluded if:

- They could not be located within the time allowed for the review;
- They exclusively studied a sample of people who had health or annoyance complaints that they attributed to wind turbines / wind farms; or
- There was no comparison group; that is, the results were not divided into two or more different exposure groups according to distance from wind turbines or SPL.

## Process of literature selection

The literature selection process is depicted through a modified PRISMA flowchart (Figure 1) (Liberati et al. 2009) that separates out the grey and black literature and indicates the amount of cross-over between passive searching (literature submitted to the NHMRC) and active searching. Literature was initially screened conservatively[16] by one reviewer for each of the grey and black literature searches, on the basis of the collated study titles and abstracts. Different reviewers were used to screen each of the searches as it was considered

[14] Definition is in the Glossary.

[15] **P**opulation/participants, **E**xposure, **C**omparator, **O**utcomes, **T**ime

[16] If the paper simply related to wind turbines and health, or related, effects it was included at the screening stage.

likely that there would be overlap in the literature that was identified by the searches and duplicate screening is preferred if the resources and time are available. Full papers of the studies deemed potentially eligible were then retrieved and independently assessed for inclusion by two reviewers. Where there was doubt about study eligibility, two senior reviewers read the paper and there was discussion between all four reviewers until a consensus decision was made. Studies that met the inclusion criteria in Box 1, but were subsequently excluded, are listed in APPENDIX C and categorised by their reason for exclusion.

### Box 1 Criteria for selecting studies to assess the impact of wind farms on human health

| Characteristic | Inclusion criteria |
|---|---|
| Study design | Studies with the designs described in Table 4 were included.[a] |
| **P**opulation/participants | People living within proximity of a wind farm / wind turbines<br>*Subgroup analysis by distance from wind farm / wind turbine* |
| **E**xposure | Physical emissions produced by wind farms / wind turbines, specifically:<br>• noise (≥20 Hz)<br>• infrasound (<20 Hz)<br>• shadow flicker (photosensitivity >3 Hz)<br>• electromagnetic radiation<br>*Subgroup analysis by level of exposure[b] for each of these exposures.* |
| **C**omparator / control (if included) | No exposure to the physical emissions produced by wind farms / wind turbines, i.e. people not living within proximity of a wind farm / wind turbine |
| **O**utcomes | Any reported adverse health effects |
| **T**ime | No restriction on the time period within which adverse health effects can be reported, with the exception that they should occur subsequent to the exposure |
| Search period | 1981[c] – 10/2012 |
| Language | English language only |

[a] Case series were excluded on the advice of the Reference Group, given the lack of any comparison group.
[b] Exposure rate or cumulative exposure (i.e. intensity or intensity x duration).
[c] First commercial wind farm established.

## Critical appraisal of selected evidence

Each systematic review question asked whether an observed association was likely to be due to bias, confounding or chance.

**Bias** is defined in the Glossary (page 181) as a systematic deviation of results or inferences from truth. In a study it relates to *an inaccuracy that differs in its size or direction in one of the groups under study than in the others ... this is a serious problem as bias can influence the results of a study in any direction. It can produce measurements of association that are exaggerated, and may produce strong associations when there is no true difference between the groups being compared*. (Elwood 2010)

Bias often occurs when there is a systematic difference between groups in the method used to assess a health outcome, whether by the person being studied, the investigator or an observer. The main principle in avoiding bias is to ensure that the same methods are used under the same circumstances for all people involved in the study. This can be achieved, where possible, through double- or single-masking techniques; that is, so that the research subject and/or the researcher are not aware of the exposure status when determining the outcome, or vice versa. This is sometimes too difficult to achieve, in which case the choice of outcome measure is important. The outcome measures must not only be relevant to the causal hypothesis, but must also be chosen to be objective, reproducible and robust (i.e. unlikely to be influenced by variations in the method of testing) (Elwood 2010).

**Confounding** is defined as *the distortion of a measure of the effect of an exposure on an outcome due to the association of the exposure with other factors that influence the occurrence of the outcome* (International Epidemiological Association 2008). Several factors were considered to be plausible confounders of 'adverse health effects', the outcome of interest in the systematic review. These plausible confounders were identified in the protocol that guided the systematic review:

- Age – If elderly people are more likely to develop heart disease (outcome) than younger people, and by chance the people living near a wind farm (exposure) who answered a health impact survey consisted of more elderly people than those living further away, it could appear that wind farm exposure was related to the development of heart disease. However, this might simply be an artefact of the unequal distribution of elderly residents in the two groups being compared.
- Gender – Risks of certain health effects (e.g. heart disease, migraine, certain cancers) are often higher in one sex than the other. Thus, a different distribution of male and female study participants in those living close to wind turbines from those living further away might result in an apparent association between wind turbine exposure and a health effect that was wholly or partly an artefact of the variation in gender distribution.

- Education – People with a poorer education often have a poorer health status, perhaps through lack of knowledge about appropriate prevention and management strategies. If there is a different distribution of people with primary, secondary and tertiary schooling according to their proximity to wind turbines, then it may result in an apparent association between wind turbine exposure and a health effect that was wholly or partly due to variation in educational attainment.
- Chronic disease – If study participants with pre-existing comorbidities and ailments or existing medication use were more likely to be located in areas designated for wind turbine construction or likely to move to an area that is near a wind turbine, this might give the appearance of an association between adverse health effects and wind turbine exposure. Similarly, differential distribution of study participants with behavioural and other risk factors for chronic disease, by distance from wind farms, could also result in an apparent association between wind turbine exposure and adverse health effects. Such risk factors include smoking (because of its relationship with numerous diseases, such as heart and other cardiovascular diseases, many lung diseases and a number of cancers) and overweight and obesity (because of their relationship with diabetes, sleep apnoea and heart disease). It is possible that there would be differences in the frequencies of these risk factors between study participants living at different distances from wind farms. It is known, for example, that people living in rural and remote regions of Australia, where wind farms are more likely to be located, often have higher rates of obesity, alcohol use and smoking than those living in more urban settings[17]. This might also be the case in other countries.
- Occupation – People who undertake shift work often have more disturbed sleep patterns and poorer health outcomes than people working 'normal' hours. Similarly, certain occupations are associated with particular health risk factors and diseases (e.g. mining and lung diseases). Therefore, if the distribution of occupations of study participants varies according to wind turbine proximity, it is possible that any apparent associations of wind turbines and health outcomes are the result of differences in 'worker profile' between those who live close to wind turbines or at a distance.
- Economic factors – The risk factors mentioned above are also more common in people of lower socioeconomic status (SES). People of lower SES tend to have a higher risk of many diseases, partly because of a greater likelihood of having disease risk factors (such as smoking, excessive use of alcohol and overweight or obesity) but also because of less tangible factors, such as their "status" in society. These people may be less likely to take actions that might prevent disease and to have less access to services that maintain health or control disease (which may also occur

[17] http://www.aihw.gov.au/rural-health-risk-factors/

with remoteness of residence). SES might confound associations between exposure to wind turbines and health effects in at least two ways. First, it is plausible that a higher proportion of people living close to wind turbines are gaining financially from having turbines sited on their land and that confounding of economic gain with wind turbine exposure might lead to fewer health effects in people living near wind farms. Second, there might be a higher proportion of people of lower SES living close to wind turbines because those of higher SES have been able to move away. While this, of itself, would increase the proportion of lower SES people close to wind turbines, the movement of higher SES people could lead to lower cost housing nearer wind turbines and attract lower SES people there.

Other factors identified and addressed in some of the studies collated for this review include terrain, urbanisation, background noise, noise sensitivity, turbine visibility, household clustering, housing, and residence duration. Depending on the associations being tested, some of these factors were considered as potential confounders of health outcomes, while others were considered as potential confounders of annoyance outcomes.

Confounding can be prevented by prospectively randomly allocating people to the different groups—if the sample size is large enough, both known and unknown confounders will generally be equally distributed between the exposure groups. It can also be prospectively addressed in cohort studies through matching individuals in the different groups according to known confounders. Neither of these study designs was presented in the direct evidence available for this review.

In observational studies of the kind typically provided to investigate the association of wind turbine exposure and adverse health effects in this review, confounding was usually addressed by analysis within strata of the confounding variable, or statistical adjustment (usually by way of a regression model of some kind) of the observed results for the effects of one or more measured confounders. Unknown or unmeasured confounders cannot be controlled in such studies and control of measured confounders is incomplete if measurement is inaccurate.

The other factor that can influence the validity of an association between exposure and outcome is **chance** variation; that is, an association might be observed simply because of chance variation in the distribution of exposure or outcome in the groups being compared. Statistical 'significance' testing is aimed at determining whether the difference in outcome between different exposure groups is larger than would be expected to occur purely by chance. This is usually represented by a probability value (*P* (or p) value), which is an estimate of the probability that an observed association has occurred by chance (e.g., if a p value = 0.001, the probability that the observed association has occurred by chance is estimated to be 1 in 1000). Confidence intervals (CI) are also used to express the possible effects of chance on an estimated statistical measure (e.g. incidence rate or relative risk).

They estimate the interval within which the 'true' or population value of the measure falls most of the time (e.g. 95% of the time for a 95% CI and 99% of the time for a 99% CI). In summary, p values and CIs attempt to quantify the degree of uncertainty in a statistic; in this review this is mostly a measure of the association between an exposure and an outcome.

To evaluate the influence of these three factors on the results of the studies included in this review, two complementary approaches were used.

Each included study was categorised according to NHMRC aetiology levels of evidence, as described in Table 4 (Merlin, Weston & Tooher 2009; NHMRC 2008). This hierarchy is included in the FORM grading system (see below) and indicates the degree to which study results are likely to be affected by different types of bias simply because of the way the study has been designed. For example, the results of cross-sectional studies are often affected by recall bias[18], so they are placed at the bottom of the hierarchy. Prospective cohort studies prospectively define how health outcomes are to be measured, and for this reason (among others) they are placed near the top of the hierarchy.

It was determined *a priori* that study quality would be appraised using an adaptation of the checklist by Downs and Black, which has been validated for use across multiple study designs, both experimental and observational controlled studies that assess interventions (Downs & Black 1998). It also contains enough detail to ensure that potential confounders are identified, and that the impact of bias and chance are specifically addressed. However, as no controlled studies were identified during the review, an NHMRC checklist (Box 9.1 in NHMRC 2000)—which was designed to critically appraise aetiology or risk factor studies—was used to assess the studies for influence of bias and confounding (incorporated within Table 7, page 46). The effect of chance on study results was considered when interpreting the statistical analyses presented. Two reviewers critically appraised each of the included studies independently, and a summary judgement was made regarding the methodological quality. When there was a lack of consensus, two senior reviewers were consulted and the study was re-appraised and discussed until a consensus decision was obtained.

[18] Recall bias (or response bias) is a difference between compared groups in the accuracy with which they report past events, or personal behaviour or experience, in response to questions.

### Table 4 NHMRC evidence hierarchy: designations of levels of evidence (excerpt)—aetiology research question only

| Level | Aetiology[a] |
|---|---|
| **I[b]** | A systematic review of level II studies |
| **II** | A prospective cohort study |
| **III-1** | All or none[c] |
| **III-2** | A retrospective cohort study |
| **III-3** | A case-control study |
| **IV** | A cross-sectional study or case series |

[a] Definitions of these study designs are provided on pages 7–8 in *How to use the evidence: assessment and application of scientific evidence (NHMRC 2000)* and in its accompanying Glossary.

[b] A systematic review will only be assigned a level of evidence as high as the studies it contains, excepting where those studies are of level II evidence. Systematic reviews of level II evidence provide more data than the individual studies, and any meta-analyses will increase the precision of the overall results, reducing the likelihood that the results are affected by chance. Systematic reviews of lower level evidence present results of likely poor internal validity, and thus are rated on the likelihood that the results have been affected by bias rather than whether the systematic review itself is of good quality. Systematic review quality should be assessed separately. A systematic review should consist of at least two studies. In systematic reviews that include different study designs, the overall level of evidence should relate to each individual outcome/result, as different studies (and study designs) might contribute to each different outcome.

[c] All or none of the people with the risk factor(s) experience the outcome; and the data arises from an unselected or representative case series that provides an unbiased representation of the prognostic effect. For example, no smallpox develops in the absence of the specific virus; and clear proof of the causal link has come from the disappearance of smallpox after large-scale vaccination.

Sources: Merlin, Weston and Tooher (2009); NHMRC (2008)

## Data extraction and synthesis

Relevant data were independently extracted by two reviewers from the included studies, using the data extraction form proposed by the NHMRC but modified to address questions of aetiology (APPENDIX B).

The studies available were limited and heterogeneous and so could not be combined quantitatively in meta-analysis. The review findings were, therefore, synthesised into an overall narrative that addressed each of the review questions, with better quality studies given greater credence in the development of conclusions. This synthesis was informed by the use of the NHMRC Evidence Statement FORM grading system (Hillier et al. 2011; NHMRC 2008). FORM was amended to more clearly indicate that the factor under study was an exposure rather than an intervention, and that the aim was to elucidate the nature of the association between a health outcome and a potential causative factor.

The FORM system allows the evidence to be appraised in terms of methodological rigour (level of evidence and likelihood of bias and confounding)[19], consistency of results, magnitude and precision of the estimates of human health effects, and generalisability and applicability of the findings to the Australian context. On the basis of this appraisal, the body of evidence to address each systematic review question is rated A to D, with an A rating indicating good support and a D rating indicating poor support for the association being tested (see Box 2). Evidence Statement Forms[20] were used to synthesise the body of evidence for each systematic review question and to draw a conclusion; these are given in each relevant 'exposure' chapter in the 'Results' section of this document. As the system is primarily intended for the development of clinical practice guidelines, evidence statements, as opposed to recommendations, were developed for the consideration of the Reference Group.

Box 2 Rating method used to determine degree of support for an association *(adapted from NHMRC FORM system)*

| Evidence statement rating | Description |
|---|---|
| A | Findings from the body of evidence can be trusted. |
| B | Findings from the body of evidence can be trusted in most situations. |
| C | The body of evidence has limitations and care should be taken in the interpretation of findings. |
| D | The body of evidence is weak and findings cannot be trusted. |

All of the evidence obtained was categorised and interpreted in the context of epidemiological guidelines developed by Austin Bradford Hill (and modified by Howick, Glasziou and Aronson (2009)) to determine likely cause and effect in the absence of experimental evidence. These Guidelines suggest complementing the available direct evidence of the impact of an exposure or intervention (such as wind turbines) on an outcome (such as adverse health effects) with mechanistic and parallel evidence, in order to determine likely cause and effect (see Table 5). Mechanistic evidence consists of studies that investigate the alleged causal mechanism that connects the exposure to health outcomes. Parallel evidence consists of studies that have similar results and so provide support for a causal hypothesis.

[19] See 'Critical appraisal of selected evidence' section above.

[20] Adapted from the NHMRC FORM grading system.

For our review of the plausible health effects of wind turbines, the 'direct evidence' consisted of the evidence addressing the systematic literature review questions. The background review questions were concerned with the physiological mechanisms by which noise, shadow flicker and EMR might produce adverse health effects ('mechanistic evidence'), and whether any health effects have been observed from noise, shadow flicker and EMR produced by exposures other than wind turbines ('parallel evidence').

Table 5 Conceptual framework to determine causality (modified Bradford Hill Guidelines)

| Type of evidence | Guidelines |
|---|---|
| **Direct**<br>*[evidence assesses impact of exposure on health outcomes]* | • Size of health effect not attributable to plausible confounding[21]<br>• Appropriate temporal proximity—cause precedes health effect and effect occurs after a plausible interval<br>• Appropriate spatial proximity—health effect occurs at the same location as the exposure<br>• Dose-responsiveness—health effect changes according the intensity of the exposure<br>• Reversibility—the health effect possibly produced by an exposure can be reversed by its removal |
| **Mechanistic**<br>*[evidence investigates mechanisms that are supposed to connect the exposure to the health outcomes]* | • Mechanism of action (biological, chemical, mechanical)—can explain the association between the exposure and the purported health effect<br>• Coherence—proposed mechanism of action (causal hypothesis) is consistent with, and is not contradicted by, other current scientific knowledge |
| **Parallel**<br>*[related studies that have similar results]* | • Replicability—the impact of the exposure on health outcomes can be replicated in independent research conducted in exactly the same way as the original research<br>• Similarity—all studies investigating the effect of the exposure on health outcomes report similar results |

Source: Howick, Glasziou and Aronson (2009)

## Quality assurance

Upon completion, the review document underwent an independent methodological review and was rated as good quality by the National Collaborating Centre for Environmental Health (NCCEH) in Canada.

[21] Distortion of the association between an exposure and a health outcome by a third factor or variable (confounder) that is related to both.

# RESULTS OF SEARCHES

## Background review questions *(mechanistic and parallel evidence)*

The questions providing contextual information for this review of the association between wind farms and human health effects do not require a stepped and documented study-selection approach. These questions were intended to elicit general information about the characteristics of wind turbines that might contribute to interpretation of the direct evidence identified through systematic literature review. The background literature obtained was consolidated and summarised; in-text citations were used to support all key statements.

## Systematic review questions *(direct evidence)*

The black literature search identified a total of 1778 references; after review of titles and abstracts against the pre-specified eligibility criteria (Box 1, page 33), 30 remained as possibly relevant articles. After full-text retrieval of these 30 articles, 13 were excluded as they were not studies[22]. A further 10 studies were excluded for the following reasons: 4 considered an exposure that was not relevant for this review (i.e. noise exposure other than living in the vicinity of a wind turbine), 2 included the wrong comparator (response to industrial and transportation noise), 1 used an unsuitable study design (qualitative design), 1 was a duplicate of another included work, 1 did not measure a health outcome and 1 was not written in English (see excluded studies, APPENDIX C). The remaining 7 articles from the black literature search, reporting on 4 studies, met the pre-specified eligibility criteria and so were included in this review (Bakker et al. 2012; Pedersen 2011; Pedersen & Larsman 2008; Pedersen et al. 2009; Pedersen & Persson Waye 2004, 2007; Shepherd et al. 2011). The study selection process is depicted in Figure 1.

The search of grey literature databases identified a total of 1070 references (Figure 1); after exclusion based on type of article, title or abstract, there were 121 articles remaining that were potentially eligible. It was noted that there was considerable overlap of articles retrieved by the grey and black literature searches. Websites, abstracts from conference proceedings, technical documents and theses were assessed against the inclusion criteria. After retrieving 121 potentially relevant documents, 93 were excluded because they were not studies[23]. Of the remaining 28 articles, 9 were excluded as they considered non-health outcomes and 8 because they duplicated results from studies previously identified, 2 studies considered populations with an irrelevant exposure, 2 had an unsuitable study design

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[22] Five articles were commentary/opinion papers, 3 were narrative reviews, 3 discussed wind energy, 1 contained wind turbine background material, and 1 discussed wind farm regulations.

[23] Twenty-six were discussion articles on wind energy, 20 were commentary/opinion papers, 19 were narrative reviews, 14 discussed guidelines or regulations, and 14 provided background on wind turbines.

(qualitative design; case reports), and 1 was excluded as it was not written in English[24]. Conference abstracts identified as potentially being eligible were found to be either published later in full as technical papers or published in the peer-reviewed literature.

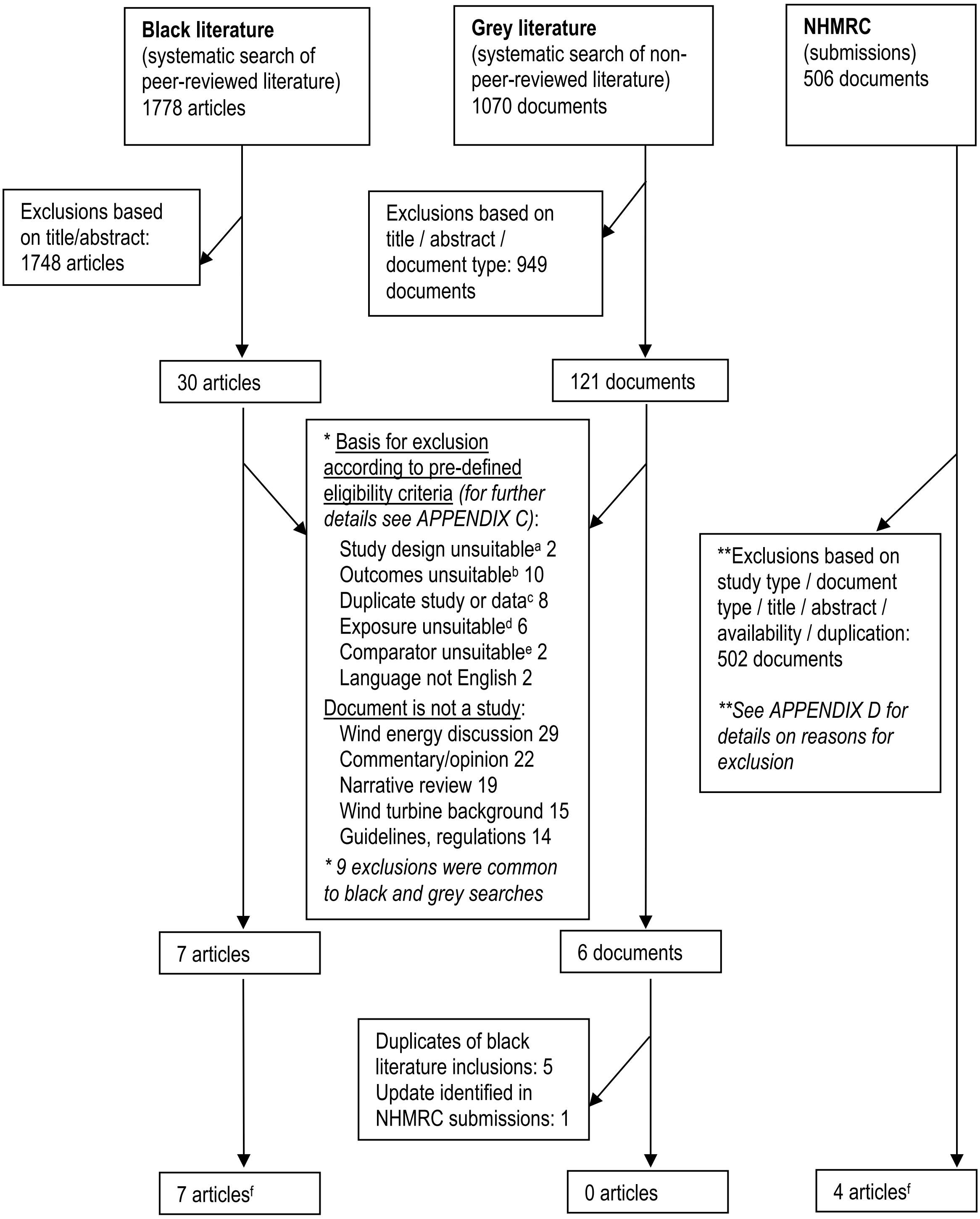
Of those articles that were considered possibly eligible (30 black and 121 grey articles), there were 9 excluded that were common to both the black and grey searches. Six relevant articles were identified in the grey literature database search. Of these, 5 were duplicates of studies included from the black literature search. The remaining article by Nissenbaum, Aramini and Hanning (2011) was updated by a more recent version submitted to the NHMRC (Nissenbaum, Aramini & Hanning 2012) (see below). Hence, no additional articles from the grey literature search were eligible to contribute to the total evidence-base.

In addition to the systematic search, submissions of grey or published literature were provided by the NHMRC to AHTA for consideration in the review (APPENDIX D). These submissions included material from NHMRC files on wind farms and human health, material that had been previously submitted to the NHMRC by stakeholders, and material that was submitted to the NHMRC for consideration in the review during the public call for literature conducted in September 2012 (hereafter referred to collectively as 'the submissions'). Some of the submissions were websites or citations for which the full text needed to be retrieved. Of the 506 submissions, the full text of 5 documents was either not found or not sighted in time for inclusion in this review. Ten submissions were considered to fit the selection criteria determined *a priori* (and were not already identified or included) for this review; 6 of which were subsequently excluded. One of these (Phipps, McCoard & Fisher 2008) reported on preliminary results from a survey on the visual and noise effects of wind turbines; however, on further investigation it was determined that health outcomes were not reported. A study by Nissenbaum, Aramini and Hanning (2012) was identified in the submitted literature which updated an older version identified in the systematic grey literature search (also referred to above). Wang (2011) provided information on the same study as Morris (2012). Harry (2007), Iser (2004) and Pierpont (2009) were case reports and case series, and so were excluded on the advice of the Reference Group (see page 30).

Thus, overall, 4 articles were included in this review from submissions, 3 of which were individual studies (Krogh et al., 2011; Morris 2012; Nissenbaum, Aramini & Hanning 2012), while 1 provided additional data to the study by Bakker et al. (2012) found in the black literature search (van den Berg et al. 2008).

In total, the black, grey and submitted literature yielded 7 studies that were discussed in 11 articles that met the criteria for inclusion in this review (see flowchart, Figure 1).

[24] An English translation was identified and the reference was found not to be a study.




[a] Study design unsuitable—qualitative study design; case reports

[b] Outcomes unsuitable—sound or noise level measures, sound directivity, attitude or other non-health-related outcomes

[c] Duplicate study or data—the study duplicates the work or data reported in a previously identified and included study

[d] Exposure unsuitable—exposure is noise from sources other than wind turbines

[e] Comparator unsuitable—comparisons between groups exposed to different noise sources

[f] **The 11 included articles reported on a total of 7 studies.**

**Figure 1 Process of study selection according to eligibility criteria in Box 1**

The results of three of the studies (SWE-00, SWE-05, NL-07), which shared aspects of a common protocol, were distributed across seven publications (see Table 6). These and the other studies provide evidence regarding the effects of noise from wind turbines on health or other factors that may relate to health, such as annoyance. In addition to the effects of noise, one study reported results for the effects of shadow flicker on annoyance. No studies were identified that explicitly considered the effects on human health of 'infrasound and low-frequency noise' or 'electromagnetic radiation' produced by wind turbines.

No other physical emissions associated with adverse health effects were apparent from the literature obtained.

Table 6 Evidence map of literature obtained to answer the systematic review questions

| Study identifier | Most comprehensive report | Study location | Articles contributing additional data on the study and/or providing additional analyses or comparisons between studies |
|---|---|---|---|
| NL-07 | Bakker et al. (2012) | The Netherlands | Van den Berg et al. (2008)<br>Pedersen et al. (2009)<br>Pedersen (2011) |
| Krogh et al. (2011) | Krogh et al. (2011) | Ontario, Canada | |
| Morris (2012) | Morris (2012) | South Australia | |
| Nissenbaum, Aramini and Hanning (2012) | Nissenbaum, Aramini and Hanning (2012) | Maine, USA | |
| SWE-00 | Pedersen and Persson Waye (2004) | Sweden | Pedersen and Larsman (2008)<br>Pedersen (2011) |

| | | | |
|---|---|---|---|
| SWE-05 | Pedersen and Persson Waye (2007) | Sweden | Pedersen and Larsman (2008)<br>Pedersen (2011) |
| Shepherd et al. (2011) | Shepherd et al. (2011) | New Zealand | |

Profiles of each of the 7 included studies, and references to the articles reporting on each, are given in Table 7. In Table 7 attention is given to the domains suggested by the NHMRC for the quality appraisal of aetiologic or risk factor studies, along with assessments of bias, confounding, chance and overall study quality. More detailed information on outcome measurement and the results obtained in these studies is given in each of the 'emission' chapters to follow. Additional information on each of the articles is provided in APPENDIX B.

## Table 7 Profile of the studies included to address the systematic review questions *(critical appraisal adapted from NHMRC 2000, Box 9.1)*

*Further details on the included studies and the study results are given in the chapters that are specific to the different exposures.*

| **Study identification** | **The Netherlands**<br>**NL-07**<br>**Bakker et al. (2012)** | **Ontario, Canada Krogh et al. (2011)** | **Australia**<br>**Morris (2012)** | **Maine, USA**<br>**Nissenbaum, Aramini and Hanning (2012)** | **Sweden**<br>**SWE-00**<br>**Pedersen and Persson Waye (2004)** | **Sweden**<br>**SWE-05**<br>**Pedersen and Persson Waye (2007)** | **New Zealand**<br>**Shepherd et al. (2011)** |
|---|---|---|---|---|---|---|---|
| **Study type** | Cross-sectional self-report questionnaire<br><br>N=725 | Cross-sectional self-report questionnaire<br><br>N=109 | Cross-sectional self-report questionnaire<br><br>N=93 households | Cross-sectional self-report questionnaire<br><br>N=79 | Cross-sectional self-report questionnaire<br><br>N=351 | Cross-sectional self-report questionnaire<br><br>N=754 | Cross-sectional self-report questionnaire<br><br>N=198 |
| **Articles contributing additional data**[a] | **Van den Berg et al. (2008)**<br>**Pedersen et al. (2009)**<br>**Pedersen (2011)** | | | | **Pedersen and Larsman (2008)**<br>**Pedersen (2011)** | **(Pedersen and Larsman (2008)**<br>**Pedersen (2011)** | |
| **Characteristics of population and study setting** | Dutch population living in rural and urban settings within 2.5 km of wind turbines<br><br>Mean age = 51 years | Residents in 5 project areas in Ontario, Canada where adverse health effects had been anecdotally reported | Households within 10 km of Waterloo wind farm, South Australia<br><br>No population characteristics reported | Residents of Mars Hill and Vinalhaven Maine, USA – locations of wind farms<br><br>Mean age of 'far' group older than | Residents of southern Sweden living 150–1199 m from wind turbines<br><br>Mean age = 48±14 years | Swedish population residing in wind turbine areas with differing terrain and levels of urbanisation | Residents of Makara Valley, New Zealand living <2km or ≥8 km from a wind turbine<br><br>Age distribution by |

| **Study identification** | **The Netherlands**<br>**NL-07**<br>**Bakker et al. (2012)** | **Ontario, Canada**<br>**Krogh et al. (2011)** | **Australia**<br>**Morris (2012)** | **Maine, USA**<br>**Nissenbaum, Aramini and Hanning (2012)** | **Sweden**<br>**SWE-00**<br>**Pedersen and Persson Waye (2004)** | **Sweden**<br>**SWE-05**<br>**Pedersen and Persson Waye (2007)** | **New Zealand**<br>**Shepherd et al. (2011)** |
|---|---|---|---|---|---|---|---|
| | % male = 51 | Fluency in English required<br><br>Mean age = 52 years<br><br>% male = 48 | | 'near' group<br><br>% male 'near' group = 58<br>% male 'far' group = 44 | % male = 42 | Mean proximity to turbines = 780±233 m<br><br>Mean age = 51±15 years<br><br>% male = 44 | group given in APPENDIX B<br><br>% male 'near' group = 41<br>% male 'far' group = 41 |
| **Exposure considered** | Modelled sound pressure level outside residences near wind turbines in dB(A)<br><br>Averaged over time with 8 m/s downwind; range = 21–54 dB(A), mean = 35 dB(A)<br><br>Grouped into five dB(A) categories: | Exposure to wind turbines (noise levels not reported)<br><br>All residences located within 2.4 km of wind turbines<br><br>Distance from turbine: 350–490 m, 24%; 55–673 m, 23%; | Exposure to wind turbines (noise levels not reported)<br><br>Residences located within 10 km of wind turbines of wind turbines; subgroup within 0–5 km | Estimated sound levels due to wind turbines - derived from a four-season study conducted 2 years previously<br><br>Measurements were taken at specific distances and expressed as $LA_{eq,\ 1\ hour}$ | Modelled sound pressure levels in dB(A) outside residences located near wind turbines<br><br>Grouped into six dB(A) categories: <30, 30–32.5, 32.5–35, 35–37.5, 37.5–40 and >40 dB(A) | Modelled sound pressure levels in dB(A) estimated outside residences located near wind turbines<br><br>Based on downwind conditions (±45°) with wind speed 8 m/s at height 10 m | Exposure to wind turbines (noise levels estimated 24–54 dB(A))<br><br>Exposed participants in dwellings (n=56 homes) <2 km from the nearest wind turbine; non-exposed controls resided (n=250 homes) ≥8 km |

| **Study identification** | **The Netherlands**<br><br>**NL-07**<br><br>**Bakker et al. (2012)** | **Ontario, Canada Krogh et al. (2011)** | **Australia**<br><br>**Morris (2012)** | **Maine, USA**<br><br>**Nissenbaum, Aramini and Hanning (2012)** | **Sweden**<br><br>**SWE-00**<br><br>**Pedersen and Persson Waye (2004)** | **Sweden**<br><br>**SWE-05**<br><br>**Pedersen and Persson Waye (2007)** | **New Zealand**<br><br>**Shepherd et al. (2011)** |
|---|---|---|---|---|---|---|---|
| | <30, 30–35, 36–40, 41–45, >45 dB(A) | 700–808 m, 30%; 900–2400 m, 17% | | Range = 32–52 dB<br><br>Two exposure groups: 'near' within 1.5 km of turbines; 'far' group 3–7 km from turbines | | Respondents' dwellings grouped in five dB(A) categories: <32.5, 32.5–35.0, 35.0–37.5, 37.5–40 and >40 dB(A) | from a turbine |
| **Effects or outcomes considered** | **Bakker et al. 2012** Sleep disturbance, psychological distress scores (GHQ-12), annoyance outside, annoyance inside<br><br>**Van den Berg et al. (2008):**<br>(a) psychological distress (GHQ-12 score and stress score); (b) any | Self-reported adverse effects—altered quality of life, altered health, disturbed sleep, excessive tiredness, tinnitus, stress, headaches, migraines, hearing problems, heart palpitations, anxiety, depression, distress, and whether they had | Annoyed by flickering, disturbed sleep, sleep quality, ear pain/pressure, tinnitus, headache, nausea, high blood pressure | Sleep quality (ESS and PSQI scales); physical and mental health (SF-36v2 scale) | Perception of noise and annoyance due to turbine sound<br><br>**Pedersen & Larsman (2008):**<br>Influence of noise level, visual attitude and general attitude on annoyance<br><br>**Pedersen (2011):**<br>Annoyance, sleep | Perception of noise; annoyance with noise<br><br>**Pedersen and Larsman (2008):**<br>Influence of noise level, visual attitude and general attitude on annoyance<br><br>**Pedersen (2011):**<br>Annoyance, sleep interruption, | QoL as per WHO quality of life scale (brief version)—WHOQOL-BREF—which includes self-reported general health<br><br>Additional outcomes on amenity, annoyance, noise sensitivity, neighbourhood problems |

| **Study identification** | **The Netherlands**<br>**NL-07**<br>**Bakker et al. (2012)** | **Ontario, Canada Krogh et al. (2011)** | **Australia**<br>**Morris (2012)** | **Maine, USA**<br>**Nissenbaum, Aramini and Hanning (2012)** | **Sweden**<br>**SWE-00**<br>**Pedersen and Persson Waye (2004)** | **Sweden**<br>**SWE-05**<br>**Pedersen and Persson Waye (2007)** | **New Zealand**<br>**Shepherd et al. (2011)** |
|---|---|---|---|---|---|---|---|
| | chronic disease, diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, migraine and sleep quality; (c) annoyance due to visual factors and vibration<br><br>**Pedersen et al. (2009):**<br>Response (do not notice/annoyance) to wind turbine noise outdoors and indoors, and attitude to wind turbines<br><br>**Pedersen 2011:** | approached a doctor | | | interruption, chronic disease, diabetes, high blood pressure, cardiovascular disease, tinnitus, impaired hearing, headache, undue tiredness, tense and stressed, irritable | chronic disease, diabetes, high blood pressure, cardiovascular disease, tinnitus, impaired hearing, headache, undue tiredness, tense and stressed, irritable | |

| **Study identification** | **The Netherlands**<br>**NL-07**<br>**Bakker et al. (2012)** | **Ontario, Canada Krogh et al. (2011)** | **Australia**<br>**Morris (2012)** | **Maine, USA**<br>**Nissenbaum, Aramini and Hanning (2012)** | **Sweden**<br>**SWE-00**<br>**Pedersen and Persson Waye (2004)** | **Sweden**<br>**SWE-05**<br>**Pedersen and Persson Waye (2007)** | **New Zealand**<br>**Shepherd et al. (2011)** |
|---|---|---|---|---|---|---|---|
| | Annoyance, sleep interruption, chronic disease, diabetes, high blood pressure, cardiovascular disease, tinnitus, impaired hearing, headache, undue tiredness, tense and stressed, irritable | | | | | | |
| **Evaluation criteria** | | | | | | | |
| **Are the study participants well defined in terms of time, place and personal characteristics?**<br><br>**[exposure** | Partly—in terms of place *(and in personal characteristics in van den Berg et al. 2008, see APPENDIX B)*<br><br>Personal | Partly—in terms of place<br><br>Personal characteristics:<br>Age and gender only personal characteristics | Partly—in terms of place<br><br>Personal characteristics:<br>None reported<br><br>Place: All residents | Partly—in terms of place<br><br>Personal characteristics:<br>Age and gender only personal characteristics | Partly—in terms of personal characteristics and place<br><br>Personal characteristics:<br>Age, gender, residence, | Partly—in terms of personal characteristics and place<br><br>Personal characteristics:<br>Age, gender, residence type and | Partly—in terms of personal characteristics and place<br><br>Personal characteristics:<br>Age, gender, education, |

| **Study identification** | **The Netherlands**<br>**NL-07**<br>**Bakker et al. (2012)** | **Ontario, Canada**<br>**Krogh et al. (2011)** | **Australia**<br>**Morris (2012)** | **Maine, USA**<br>**Nissenbaum, Aramini and Hanning (2012)** | **Sweden**<br>**SWE-00**<br>**Pedersen and Persson Waye (2004)** | **Sweden**<br>**SWE-05**<br>**Pedersen and Persson Waye (2007)** | **New Zealand**<br>**Shepherd et al. (2011)** |
|---|---|---|---|---|---|---|---|
| **misclassification]** | characteristics: Age not reported by exposure status (only the overall mean provided), gender and location of residence described<br><br>Place: All residents lived within 2.5 km of wind turbines. Noise exposure was modelled<br><br>Time: This is a cross-sectional study with self-reported outcome measures; therefore, it cannot be | described<br><br>Place: All residents live within 2.4 km of wind turbines<br>Distance as a proxy for noise exposure<br><br>Time: This is a cross-sectional study with self-reported outcome measures; therefore, it cannot be determined objectively whether wind farm exposure preceded the reported outcome(s) | live within 10 km of wind turbines<br>Distance as a proxy for noise exposure<br><br>Time: This is a cross-sectional study with self-reported outcome measures; therefore, it cannot be determined objectively whether wind farm exposure preceded the reported outcome(s) | described<br><br>Place: Two exposures: 'near' within 1.5 km of turbines; 'far' group 3–7 km from turbines. Noise exposure was estimated from previous research at the site<br><br>Time: This is a cross-sectional study with self-reported outcome measures; therefore, it cannot be determined objectively whether wind | occupation, noise sensitivity, attitude to turbines and long-term illness described<br><br>Place: All residents lived 150–1199 m from wind turbines.<br>Noise exposure was modelled<br><br>Time: This is a cross-sectional study with self-reported outcome measures; therefore, it cannot be determined objectively | duration, occupation, noise sensitivity and chronic disease status described<br><br>Place: Mean proximity to turbines = 780±233 m<br>Noise exposure was modelled<br><br>Time: This is a cross-sectional study with self-reported outcome measures; therefore, it cannot be determined objectively whether wind | employment status, noise sensitivity and current illness described<br><br>Place: Two exposure groups: 'exposed' group within 2 km of turbines; control group ≥8 km from turbines<br>Noise exposure was estimated from previous research at the site<br><br>Time: This is a cross-sectional study with self-reported outcome |

| **Study identification** | **The Netherlands**<br>**NL-07**<br>**Bakker et al. (2012)** | **Ontario, Canada Krogh et al. (2011)** | **Australia**<br>**Morris (2012)** | **Maine, USA**<br>**Nissenbaum, Aramini and Hanning (2012)** | **Sweden**<br>**SWE-00**<br>**Pedersen and Persson Waye (2004)** | **Sweden**<br>**SWE-05**<br>**Pedersen and Persson Waye (2007)** | **New Zealand**<br>**Shepherd et al. (2011)** |
|---|---|---|---|---|---|---|---|
| | determined objectively whether wind farm exposure preceded reported outcome(s) | | | farm exposure preceded the reported outcome(s). | whether wind farm exposure preceded the reported outcome(s) | farm exposure preceded the reported outcome(s) | measures; therefore, it cannot be determined objectively whether wind farm exposure preceded reported outcome(s) |
| **What percentage of individuals or clusters refused to participate?**<br><br>**[selection bias]** | 63% of those who received a questionnaire did not complete and return it<br><br>Sampling area determined by distance from wind turbines<br><br>High non-participation rate indicates a high | Not reported what proportion did not complete and return questionnaire<br><br>Sampling area was chosen because adverse health effects had been reported there<br><br>Multiple adults from same | 60% of questionnaires delivered to households were not returned<br><br>Sampling area determined by distance from wind turbines<br><br>High non-participation rate indicates a high | Of those who received a questionnaire:<br>'Near' group = 42% did not complete and return it<br>'Far' group = not reported what proportion did not complete and return it<br><br>Sampling area | 32% of those who received a questionnaire did not complete and return it<br><br>Individuals selected in pseudo-random method (one subject in each household in area, with birth date closest to 20 May) | 42% of those who received a questionnaire did not complete and return it<br><br>Sampling area determined by distance from wind turbines and type of terrain<br><br>Moderate non-participation rate | Of those who received a questionnaire:<br>'Exposed' group = 66% did not complete and return it<br><br>Control group = 68% did not complete and return it<br><br>Sampling area |

| **Study identification** | **The Netherlands**<br>**NL-07**<br>**Bakker et al. (2012)** | **Ontario, Canada**<br>**Krogh et al. (2011)** | **Australia**<br>**Morris (2012)** | **Maine, USA**<br>**Nissenbaum, Aramini and Hanning (2012)** | **Sweden**<br>**SWE-00**<br>**Pedersen and Persson Waye (2004)** | **Sweden**<br>**SWE-05**<br>**Pedersen and Persson Waye (2007)** | **New Zealand**<br>**Shepherd et al. (2011)** |
|---|---|---|---|---|---|---|---|
| | probability of selection bias which may vary depending on wind turbine exposure.<br><br>200/1223 non-responders were randomly selected for a subsequent analysis, and in the 95 'responding non-responders' there were no statistically significant differences in annoyance levels in comparison with those who responded to the primary questionnaire. | household were able to respond, so if household size differs by distance from a wind turbine this would bias the results. | probability of selection bias which may vary depending on wind turbine exposure. | determined by distance from wind turbines<br><br>Potentially different non-participation rate in the two groups. Moderate non-participation rate in "exposed" group. | Sampling area determined by distance from nearest wind turbine | indicates a probability of selection bias which may vary depending on wind turbine exposure. | determined by distance from wind turbines<br><br>High non-participation rate indicates a high probability of selection bias, so characteristics of sample may vary depending on wind turbine exposure. |

| **Study identification** | **The Netherlands**<br>**NL-07**<br>**Bakker et al. (2012)** | **Ontario, Canada Krogh et al. (2011)** | **Australia**<br>**Morris (2012)** | **Maine, USA**<br>**Nissenbaum, Aramini and Hanning (2012)** | **Sweden**<br>**SWE-00**<br>**Pedersen and Persson Waye (2004)** | **Sweden**<br>**SWE-05**<br>**Pedersen and Persson Waye (2007)** | **New Zealand**<br>**Shepherd et al. (2011)** |
|---|---|---|---|---|---|---|---|
| | **Pedersen et al. (2009):**<br>63%<br>Non-participation rate was 56-61% in the two lowest exposure categories and 67-68% in the three highest categories. | | | | | | |
| **Are outcomes measured in a standard, valid and reliable way?**<br><br>**[outcome misclassification]** | Partly—GHQ-12 used for some outcomes<br><br>GHQ-12 is a valid measure of psychiatric ill health<br><br>Remaining components of | No<br><br>The survey form designed by Harry (2007) was reproduced and used for this survey<br><br>Health outcomes were self-reported | No<br><br>A purpose-designed form was used for this survey<br><br>Health outcomes were self-reported | Partly—PSQI, ESS, SF-36v2 used<br><br>PSQI, ESS, SF-36v2 considered to be standardised and valid measures<br><br>Other parts of the questionnaire were purpose- | No<br><br>Assumed to be a purpose-designed survey created by the study authors.<br><br>Health outcomes were self-reported. | No<br><br>Assumed to be a purpose-designed survey created by the study authors.<br><br>Health outcomes were self-reported. | Partly—WHOQOL-BREF used<br><br>Used validated WHO quality of life scale (brief version) (WHOQOL-BREF) with following components: physical, |

| Study identification | The Netherlands<br>NL-07<br>Bakker et al. (2012) | Ontario, Canada<br>Krogh et al. (2011) | Australia<br>Morris (2012) | Maine, USA<br>Nissenbaum, Aramini and Hanning (2012) | Sweden<br>SWE-00<br>Pedersen and Persson Waye (2004) | Sweden<br>SWE-05<br>Pedersen and Persson Waye (2007) | New Zealand<br>Shepherd et al. (2011) |
|---|---|---|---|---|---|---|---|
| | study questionnaire were based on tool used in SWE-00 and SWE-05, excluding questions on coping strategies and with new questions on health and environment.<br><br>Health outcomes were self-reported | | | designed for the study.<br><br>Health outcomes were self-reported. | | | psychological, social and environmental<br><br>Authors added additional items which appear to be purpose-designed |
| **What percentages of individuals or clusters recruited into the study are not included in the analysis (i.e. loss to follow-up)?** | None | Four responders who were under 18 years of age, and 2 who lived further from the turbines (5 km) compared with the | None | None | None | None | None |

| **Study identification** | **The Netherlands**<br>**NL-07**<br>**Bakker et al. (2012)** | **Ontario, Canada Krogh et al. (2011)** | **Australia**<br>**Morris (2012)** | **Maine, USA**<br>**Nissenbaum, Aramini and Hanning (2012)** | **Sweden**<br>**SWE-00**<br>**Pedersen and Persson Waye (2004)** | **Sweden**<br>**SWE-05**<br>**Pedersen and Persson Waye (2007)** | **New Zealand**<br>**Shepherd et al. (2011)** |
|---|---|---|---|---|---|---|---|
| | | others, were not included in the analysis | | | | | |
| **Recall bias?** | Uncertain<br><br>Study intent was masked for respondents—unknown how effective this was | Likely<br><br>Intent of survey not masked – “affected” people were encouraged to participate | Likely<br><br>Intent of survey not masked | Likely<br><br>Intent of survey not masked | Uncertain<br><br>Study intent was masked for respondents—unknown how effective this was | Uncertain<br><br>Study intent was masked for respondents—unknown how effective this was | Uncertain<br><br>Study intent was masked for respondents—unknown how effective this was |
| **Confounding? (other factors that could affect the outcomes)** | Analyses adjusted for:<br>Age, gender, employment, terrain, urbanisation, economic benefit from turbines, background noise, noise sensitivity, attitude to turbines and | Analyses adjusted for:<br>Gender in some analyses<br><br>Other plausible confounders not addressed:<br>Economic factors, age, chronic disease and risk factors for chronic | Analyses adjusted for:<br>Nil<br><br>Other plausible confounders not addressed:<br>Economic factors, age, gender, chronic disease and risk factors for chronic disease, | Analyses adjusted for:<br>Age, gender, site, and household clustering<br><br>Other plausible confounders not addressed:<br>Economic factors, chronic disease and risk factors for | Analyses adjusted for:<br>Age, gender, noise sensitivity, visual impact, attitude to turbines in some analyses<br><br>Other plausible confounders not addressed:<br>Economic factors, | Analyses adjusted for:<br>Age, gender, employment, housing, residence duration, terrain, urbanisation, background noise, noise sensitivity, visual impact, attitude to turbines | Analyses adjusted for:<br>Length of residence (and participants selected from geographic and socio-economic matched areas)<br><br>Other plausible confounders not |

| **Study identification** | **The Netherlands**<br>**NL-07**<br>**Bakker et al. (2012)** | **Ontario, Canada Krogh et al. (2011)** | **Australia**<br>**Morris (2012)** | **Maine, USA**<br>**Nissenbaum, Aramini and Hanning (2012)** | **Sweden**<br>**SWE-00**<br>**Pedersen and Persson Waye (2004)** | **Sweden**<br>**SWE-05**<br>**Pedersen and Persson Waye (2007)** | **New Zealand**<br>**Shepherd et al. (2011)** |
|---|---|---|---|---|---|---|---|
| | turbine visibility (covariates varied between analyses)<br><br>Other plausible confounders not addressed:<br>Socioeconomic factors *(was addressed in van den Berg et al 2008)*, chronic disease and risk factors for chronic disease, and occupation | disease, occupation, education, employment, terrain, urbanisation, background noise, and turbine visibility | occupation, education, employment, terrain, urbanisation, background noise, and turbine visibility | chronic disease, occupation, education, employment, terrain, urbanisation, background noise, and turbine visibility | chronic disease and risk factors for chronic disease, occupation, education, employment, terrain, urbanisation, background noise | (covariates varied between analyses)<br><br>Other plausible confounders not addressed:<br>Economic factors, chronic disease and risk factors for chronic disease, occupation, education. | addressed:<br>Age, chronic disease and risk factors for chronic disease, occupation, employment, education, background noise, and turbine visibility |
| **Chance?** | No evidence of adjustment of p-values for multiple statistical tests | No evidence of adjustment of p-values for multiple statistical tests or for some clustering of participants in | No formal statistical tests for chance association were conducted | No evidence of adjustment of p-values for multiple statistical tests | Adjustment of p-values for multiple statistical tests using Bonferroni's method | No evidence of adjustment of p-values for multiple statistical tests | Adjustment of p-values for multiple statistical tests using Bonferroni's method<br><br>5 cases excluded |

| Study identification | The Netherlands<br>NL-07<br>Bakker et al. (2012) | Ontario, Canada<br>Krogh et al. (2011) | Australia<br>Morris (2012) | Maine, USA<br>Nissenbaum, Aramini and Hanning (2012) | Sweden<br>SWE-00<br>Pedersen and Persson Waye (2004) | Sweden<br>SWE-05<br>Pedersen and Persson Waye (2007) | New Zealand<br>Shepherd et al. (2011) |
|---|---|---|---|---|---|---|---|
| | | households | | | | | from comparator group due to being multivariate outliers |
| **Overall quality of the study to determine whether wind farms cause adverse health effects?** | **Poor**<br>High risk of:<br>• exposure misclassification<br>• selection bias<br>• significant associations due to chance<br><br>Potential for:<br>• outcome misclassification<br>• recall bias<br>• confounding | **Poor**<br>High risk of:<br>• exposure misclassification<br>• outcome misclassification<br>• recall bias<br>• selection bias<br>• confounding<br>• significant associations due to chance | **Poor**<br>High risk of:<br>• exposure misclassification<br>• selection bias<br>• outcome misclassification<br>• recall bias<br>• confounding | **Poor**<br>High risk of:<br>• exposure misclassification<br>• recall bias<br>• selection bias<br>• confounding<br>• significant associations due to chance<br><br>Potential for:<br>• outcome misclassification | **Poor**<br>High risk of:<br>• exposure misclassification<br>• outcome misclassification<br>• confounding<br><br>Potential for:<br>• recall bias | **Poor**<br>High risk of:<br>• exposure misclassification<br>• selection bias<br>• outcome misclassification<br>• significant associations due to chance<br><br>Potential for:<br>• recall bias<br>• confounding | **Poor**<br>High risk of:<br>• exposure misclassification<br>• selection bias<br>• confounding<br><br>Potential for:<br>• outcome misclassification<br>• recall bias |

Abbreviations: dB = decibels; dB(A) = A-weighted sound pressure (decibels); $LA_{eq,\ 1\ hour}$ = A-weighted noise level over 1 hour; m/s = metres per second as a measurement of wind speed; GHQ-12 = General Health Questionnaire, version 12; NA = not applicable; ESS = Epworth Sleepiness Scale; PSQI = Pittsburgh Sleep Quality Index; SF-36v2 = Short Form (36) Health Survey, version 2; NR = not reported; QoL = quality of life; WHO = World Health Organization

[a] Where additional articles contribute further information, the details are included in the column for the associated study.

# NOISE

## *BQ2. BY WHAT SPECIFIC PHYSICAL EMISSIONS MIGHT WIND TURBINES CAUSE ADVERSE HEALTH EFFECTS?*

Noise is defined as an unwanted sound or an unwanted combination of sounds. Therefore, what can be considered 'noise' will vary between individuals depending on factors such as the complex temporal pattern and intensity of the sound, cultural attitudes, timing and other circumstances (e.g. a Beethoven symphony may be music at dinner time but noise in the middle of the night if it disrupts sleep).

Sound is an energy form that travels from a source in the form of waves or pressure fluctuations transmitted through a medium and received by a receiver (e.g. human ear). Sound is perceived and recognised by its loudness (pressure) and pitch (frequency[25]). The general range for human hearing for young adults is between 20 Hz and 20 kHz, with a declining upper limit as age increases (Berglund, Hassmen & Job 1996). Human sound perception is less sensitive to lower frequency (low pitch) and higher frequency (high pitch) sounds. It is easiest for the human ear to recognise sounds in the middle of the audible spectrum (1–4 kHz) (Roberts & Roberts 2009).

The following sound thresholds have been suggested (Hawkins 2012; Thorne 2011):

- Infrasound, <20 Hz (normally inaudible)
- Low-frequency, 20–200 Hz, although the upper limit can vary (Leventhall 2006; O'Neal, Hellweg & Lampeter 2011)
- Mid-frequency, 200–2000 Hz
- High-frequency, 2–20 kHz.

The decibel (dB) is an indicator of loudness (amplitude) calculated as the logarithmic ratio of sound pressure level (SPL)[26] to a reference level (Roberts & Roberts 2009). Sound pressure is a property of sound *at a given observer location* and can be measured at that specific point by a single microphone (Rogers, Manwell and Wright 2006).

Various filters[27] can be used to weight sound pressure measurements as a function of frequency to align them with human sensitivity. The human ear simultaneously receives sound at many frequencies and at different amplitudes. The audibility of the sound varies significantly with the frequency of the sound it is receiving, in addition to the SPL of that sound. At low SPLs, low

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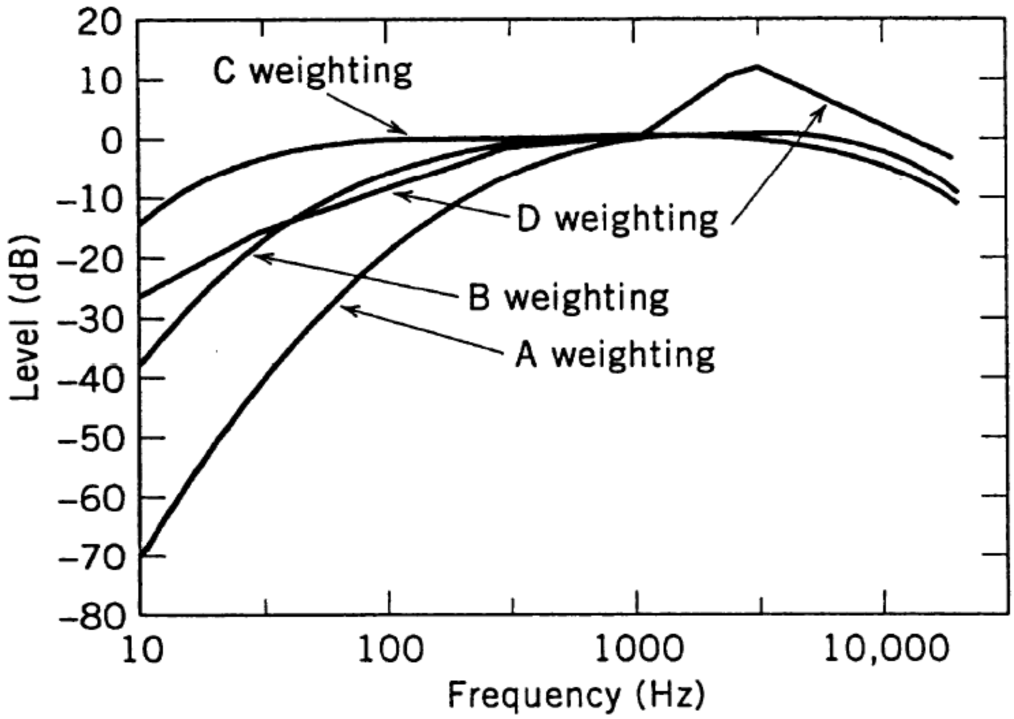
[25] Frequency is the number of sound waves/cycles passing a given point per second and is measured is cycles per second (cps), also called hertz (Hz).

[26] The sound pressure level can be calculated by using the formula SPL = $10\log_{10}[p^2/p_{ref}^2]$ where $p_{ref}$ is the reference pressure or 'zero' reference for airborne sound ($20\times10^{-6}$ pascals)

[27] A filter is a device that modifies a sound signal by attenuating some of its frequency components (Jacobsen et al. 2011)

frequencies are less audible than medium frequencies (Jacobsen et al. 2011). The standardised frequency weighting filters are depicted in Figure 2.

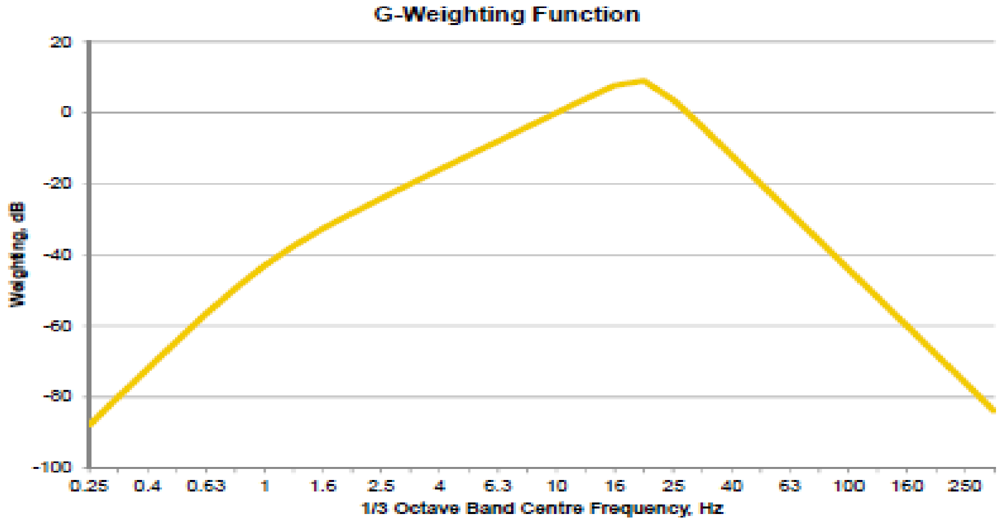



Source: Figure 1.3.7, Jacobsen et al. (2011)

**Figure 2 Standardised frequency weighting curves**

The A-weighted SPL is the most widely used single-value measure of sound. A-weighted measurements are common because they generally align with the subjective response to noise. However, the A-weighted filter is 'less sensitive' to very-high- and very-low-frequency sound. The C-weighted filter is essentially 'flat' in the audible frequency range, but is 'more sensitive' in the low-frequency range than the A-weighted filter. Therefore, a large difference between the A-weighted level and the C-weighted level is a clear indication of prominent content of low-frequency noise (Jacobsen et al. 2011). B-weighted and D-weighted filters are not often used.

The G-weighting function is used to quantify sound that has a significant portion of its energy in the infrasonic range. The function weights noise levels between 0.25 Hz and 315 Hz to reflect human perception of infrasonic noise levels (Verrotti et al. 2005). Figure 3 (reproduced from Evans, Cooper & Lenchine (2013)) depicts the G-weighting function across this frequency range. The weighting shown is applied directly to the unweighted noise levels. The perception of sound in the infrasonic range is greatest at 20 Hz, with a reduction as the frequency decreases.




Source: Figure 2, Evans, Cooper and Lenchine (2013)

**Figure 3 G-weighting function across 1/3 octave band frequency (Hz)**

## Sound perception and distance

Measurements of sound from a particular source vary according to the distance from the source. Sound pressure decreases with distance (*r*) from a point source in an inverse (1/*r*) relationship, and sound intensity[28] decreases in a relationship of $1/r^2$ according to the *inverse distance law* (Jacobsen et al. 2011). In effect, when distance is doubled, the sound pressure value is reduced to one-half of its initial value (50%) and the sound intensity value is reduced to one-quarter of its initial value (25%). Because of the decrease in sound pressure with distance, it is important to consider distance from the source when assessing the impact of sound or noise.

Due to the predictable decrease in sound pressure with increasing distance from a source, it is possible to use distance as a proxy for SPL measures. It should be noted, however, that, in addition to distance from the source, wind direction, terrain, temperature and time of day can affect sound levels. Another characteristic of sound is that longer wavelengths (low-frequency) travel further through most media (e.g. air, water) than shorter wavelengths, and generally show less attenuation than shorter wavelengths when travelling through solid media such as walls and windows (Persson Waye 2004). This characteristic is relevant to the consideration of sound produced by wind turbines, given that residences are usually at a distance from turbines.

[28] The sound intensity can be defined as the sound power per unit area at a point on a radiating sound wave. Sound intensity is not the same physical quantity as sound pressure. Hearing is directly sensitive to sound pressure, which is related to sound intensity (Jacobsen et al. 2011).

## Infrasound and low-frequency noise (ILFN)

The definitions of infrasound and low-frequency noise (ILFN), and what can be termed as audible and inaudible, are summarised below (O'Neal, Hellweg & Lampeter 2011; Watanabe & Møller 1990; Berglund, Hassmen & Job 1996):

- There is no clear definition of the upper limit of low-frequency sound. The definitions vary and can range from 100 Hz to 250 Hz.
- Sound <20 Hz is generally termed infrasound and is not considered in the low-frequency range, on the basis that infrasound is considered inaudible in normal environments. However, the hearing threshold is dependent on the frequency and level of the sound and frequencies well below 20 Hz can be audible if the amplitude of the SPL is high enough. In addition there is inter-individual variation in hearing thresholds.
- For sounds to be audible at frequencies <20 Hz, they need to have an amplitude of >80 dB. For example, at a frequency of 5 Hz the amplitude would need to be higher than 103 dB.

## Mechanisms by which noise might affect health

Noise has the potential to affect health through stress and hearing loss.

Biological studies of the impact of noise that is sufficiently loud to cause hearing loss are, in general, well documented in the scientific literature (Azizi 2010). Noise-induced pathology as a result of higher metabolic activity was originally proposed in the 1970s (Lim & Melnick 1971). It was suggested that noise-induced hearing loss (NIHL) might be the consequence of oxidative stress such that there is an initial increase in the rate of cochlear blood flow, followed by capillary vasoconstriction and an abrupt decrease in cochlear circulation, leading to a subsequent increase in metabolic activity and enhanced production of free radicals (Seidman & Standring 2010). Free radicals, or Reactive Oxygen Species (so called when they are produced *in vivo* as a by-product of mitochondrial respiration), have the potential to lead to cell death and cause irreversible damage to hearing structures when present in excessive amounts. NIHL mainly occurs between 500 and 8000 Hz, with legal deafness assessed at 4000 Hz (Alves-Pereira & Castelo Branco 2007).

Stress is considered another mechanism by which noise can impact on human health (Babisch 2002). However, because of the individual variation in response to stressors, adaptability to stress, and the associated impact of other plausible factors (confounders) that may affect health, there is little consensus as to how noise-related stress affects health. Three key features of the stress-health process (cortisol, suppression of the immune system and psychological distress) have been measured in noise research.

Research suggests that there is no relationship between level of noise and serum cortisol level. This could be because a high noise level may act directly as a stressor, whereas low levels may only affect cortisol secretion if the noise is considered disturbing by the individual. It is also hypothesised that high cortisol concentrations may cause partial destruction of cortisol receptors in the brain, which in turn may be responsible for chronic elevation of cortisol, with long-term side effects of arteriosclerosis and immunosuppression (Prasher 2009; van Kamp et al. 2007). However, these hypothesised long-term effects could equally be a consequence of other exposures (confounders) in the same noise-producing environment, e.g. toxic substance exposure, work demands and air pollution (Selander et al. 2009; Davis & Kamp 2012; Selander et al. 2013).

Where stress effects are present, they may be dependent on the level of annoyance induced by the noise (Laszlo et al. 2012). For example, exposure to aircraft noise only increases the risk of hypertension in those who are annoyed by the noise (Eriksson et al. 2007). Babisch (2002) states that *"prolonged exposure to the same noise can lead to habituation and negative effects on performance may then disappear".*

In addition, Babisch (2002) notes that *"individuals perform better when the acute exposure matches their normal exposure. This suggests that individuals regularly exposed to noise will do worse in quiet than those from quiet environments, whereas the reverse will occur if the two groups are tested in noise"*.

Stress may also be induced by the degree of sleep disruption associated with noise. The adverse effects on sleep appear to be larger for unpredictable noise and rapidly changing noise, when compared with a predictable constant noise. The level of noise is not a predictor of a stress reaction during sleep. Stress reactions are instead associated with the meaning of the noise to the individual (Prasher 2009). Recent work has shown that individuals who generate more sleep spindles (a thalamocortical rhythm manifested on the EEG as a brief 11–15 Hz oscillation) during a quiet night of sleep exhibit higher tolerance for noise during a subsequent, noisy night of sleep. This provides strong support to the concept that there is inter-individual variation in resilience to sleep-disruptive stimuli (Dang-Vu et al. 2010).

The studies mentioned above examined sound levels in the audible frequency range. Like most noise sources, wind turbines emit multiple frequencies of sound, both infrasonic and audible. The frequency range of sound emitted from wind turbines is discussed more comprehensively below but, given that most residences are sited at a distance from wind turbines, the most relevant sound exposure is ILFN. While ILFN may not cause auditory damage, other biological damage resulting from heavy exposure to ILFN has been suggested, although it is an area of controversy (Alves-Periera et al. 2007; Leventhall 2009). The evidence for whether ILFN also produces stress effects is addressed in Background Question 4 (see page 110).

## *BQ3. FOR EACH EMISSION, WHAT IS THE LEVEL OF NOISE EXPOSURE FROM A WIND TURBINE AND HOW DOES IT VARY BY DISTANCE AND CHARACTERISTICS OF THE TERRAIN SEPARATING A WIND TURBINE FROM POTENTIALLY EXPOSED PEOPLE?*

Since concerns have been raised about human exposure to ILFN from wind turbines, it is important to determine the likely level of exposure (dose) experienced by people living in the vicinity of wind farms.

## Sound from wind turbines

Sound from wind turbines is described in the literature as either mechanical or aerodynamic (Ellenbogen et al. 2012; Roberts & Roberts 2009). These sound types are also characterised as tonal[29] or broadband[30], constant amplitude or amplitude modulated, and audible or inaudible/infrasonic (Ellenbogen et al. 2012). Turbines with downwind rotors should be distinguished from turbines with upwind rotors—early wind turbines had downwind rotors, which emitted higher levels of infrasound than turbines with upwind rotors (Rogers, Manwell and Wright 2006). Modern wind farms very rarely use the downwind design.

Mechanical sound is produced mainly from moving rotational and electrical components, including the gearbox, generator, yaw drives, cooling fans and auxiliary of the turbine. Noise from a 1500-kW turbine, with a generator speed ranging from 1100 to 1800 revolutions per minute (rpm), contains a sound tone frequency between 20 and 30 Hz (Ellenbogen et al. 2012).

Aerodynamic noise is the major component of noise from modern wind turbines, given that improvements in wind turbine design and manufacture have reduced mechanical noise to a level that is below that of aerodynamic noise (Pedersen & Persson Waye 2004, 2007; van den Berg 2004). A key source of aerodynamic sound from modern wind turbines is the trailing edge noise that originates from air flow around the components of the wind turbine (blades and tower), producing a 'whooshing' sound in the 500–1000 Hz range (Hau 2008; Roberts & Roberts 2009). This is often described as amplitude (or aerodynamic) modulation, meaning that the sound can vary due to atmospheric effects and directional propagation effects (see 'Measurement of sound from wind turbines' section below) (van den Berg 2004). Table 8 summarises the different sources of aerodynamic sound from a wind turbine as reproduced by Ellenbogen et al. (2012) from Wagner, Bareiss and Guidati (1996).

[29] Sound at discrete frequencies.

[30] Characterised by a continuous distribution of sound pressure with frequencies >100 Hz.

Table 8 Sources of aerodynamic sound from a wind turbine

| Noise type | Mechanism | Characteristic |
|---|---|---|
| Trailing-edge noise | Interaction of boundary layer turbulence with blade trailing edge | Broadband, main source of high-frequency noise (770 Hz< f <2 kHz) |
| Tip noise | Interaction of tip turbulence with blade tip surface | Broadband |
| Stall, separation noise | Interaction of turbulence with blade surface | Broadband |
| Laminar boundary layer noise | Non-linear boundary layer instabilities interacting with the blade surface | Tonal |
| Blunt trailing-edge noise | Vortex shedding at blunt trailing edge | Tonal |
| Noise from flow over holes, slits and intrusions | Unsteady shear flows over holes and slits, vortex shedding from intrusions | Tonal |
| Inflow turbulence noise | Interaction of blade with atmospheric turbulence | Broadband |
| Steady thickness noise, steady loading noise | Rotation of blades or rotation of lifting surface | Low frequency related to blade-passing frequency (outside of audible range) |
| Unsteady loading noise | Passage of blades through varying velocities, due to pitch change or blade altitude change as it rotates; for downwind turbines, passage through tower shadow | Whooshing or beating, amplitude modulation of audible broadband noise; for downwind turbines, impulsive noise at blade-passing frequency |

Abbreviations: f = frequency

Sources: Ellenbogen et al. (2012); Wagner, Bareiss and Guidati (1996)

## Measurement of sound from wind turbines

Deriving a single SPL from wind turbines in the presence of background noise is difficult. Numerous factors (e.g. meteorological conditions, wind turbine spacing, wake and turbulence effects, vortex effects, turbine synchronicity, tower height, blade length and power settings) contribute to the sound levels heard or perceived at residences. Perception of wind farm sound would also depend on any building resonance effects for residents living inside a dwelling (Thorne 2011).

### *Modelled or estimated sound pressure level*

Prediction of an SPL (a modelled SPL), at a specific distance from a wind turbine source with a known power level, requires knowledge of the propagation of sound waves. In general, the SPL decreases as sound propagates without obstruction from a point source. The SPL is reduced by 6 dB per doubling of distance. If the source is on a perfectly flat and reflecting surface, then hemispherical spreading is assumed. An accurate sound propagation model to estimate SPL usually considers the following factors (Beranek & Ver 1992; Ellenbogen et al. 2012; Rogers, Manwell & Wright 2006):

- source characteristics including directivity and height
- distance from the source
- air absorption, which depends on frequency
- ground effects (reflection/absorption of sound on the ground, which is influenced by turbine height, the terrain cover and ground properties between the source and the receiver)
- the presence of obstructions and uneven terrain
- weather effects (i.e. wind direction and speed/change, temperature variation with height)
- topography (landscape—land forms can focus sound).

Overall, using a 'conservative' assumption of a model of hemispherical propagation over a reflective surface, the following formula can be used to predict the SPL ($L_p$):

$$L_p = L_w - 10\log_{10}(2\pi r^2) - \alpha r$$

where $r$ is the distance from the sound source radiating at power level $L_w$ (dB), and $\alpha$ is the frequency-dependent sound absorption coefficient ($\alpha$ = 0.005 dB/m) (Rogers, Manwell and Wright 2006).

The total sound produced by multiple wind turbines can be estimated by summing the sound levels caused by each turbine at a specific location[31] (Rogers, Manwell and Wright 2006). For multiple wind turbines ($N$) in close proximity, the total sound power can be estimated by:

$$L_{total} = 10\log_{10}\sum 10^{L_i/10}$$

The sum $\sum$ is from turbine $i$ = 1 to $N^{th}$ turbine, and $L_i$ is the sound power of the $i^{th}$ turbine.

[31] Note that decibels cannot be added numerically as linear measures.

The calculations become more 'complicated' when distances vary between turbines in a wind farm. Ellenbogen et al. (2012) provide a comprehensive discussion on these issues in their Appendix E.

### *Turbine sound in the international setting*

The Danish Environmental Agency provided a summary of wind turbine measurements by turbine type, distance and conditions (wind, number of turbines etc.) from a number of published reports (Jakobsen 2005). These data are reproduced in Table 9. However, Jakobsen et al. (2005) noted that the measurement and operating conditions of the wind turbines were not described in detail in the individual reports, and that it was not possible to correct for background noise.

Table 9 Wind turbine measurements (conducted outdoors) by power, distance and conditions

| Wind turbine type | Power rating, kW | Distance, m | Infrasound level, dB(G) | Conditions[a] |
|---|---|---|---|---|
| Monopteros 50 | 640 | 200 | 84 | 11 m/s |
| Encercon E-40 | 500 | 200 | 56–64 | 8 m/s |
| Vestas V66 | 1650 | 100 | 70 | 723 kW |
| Unknown | 2000 | 200 | 59 | 6 m/s |
| | | 200 | 65 | 12 m/s |
| Bonus | 450 | 80 | 65 | 9 m/s (4 turbines) |
| | | 100 | 71 | 8 m/s (1 turbine) |
| | | 200 | 63 | 10 m/s (1 turbine) |
| | | 100–200 | 70 | 9 m/s (4 turbines) |
| MOD-1 | 2000 | 105 | 107 | No details provided |
| | | 1000 | 73–75 | |
| WTS-4 | 4200 | 150 | 92 | |
| | | 250 | 83–85 | |
| MOD-5B | 3200 | 68 | 71 | |
| USWP-50 | 50 | 500 | 67–79 | (14 turbines) |
| WTS-3 | 3000 | 750 | 68 | No details provided |
| | | 2100 | 60 | |

(G) = to allow easier comparison between the different findings on infrasound emission, the G-weighted infrasound level was estimated by the authors. However, there were inadequate data to control for potentially different background noise levels, i.e. the impact of background noise on the measured noise level is not known.
Abbreviations: m/s = metres per second as a measurement of wind speed
[a] For some conditions, the number of turbines is not provided.
Source: Jakobsen (2005)

Van den Berg et al. (2008) summarised SPLs from approximately 90 wind turbines in The Netherlands according to wind turbine type, power, hub height, rotor diameter and wind speed. When the data were plotted, it was apparent that, despite differences in power, hub height, rotor diameter and wind speed, the sound emission signatures were very similar across all types of wind turbine models. This was particularly the case in the mid-frequency range, 500–1000 Hz.

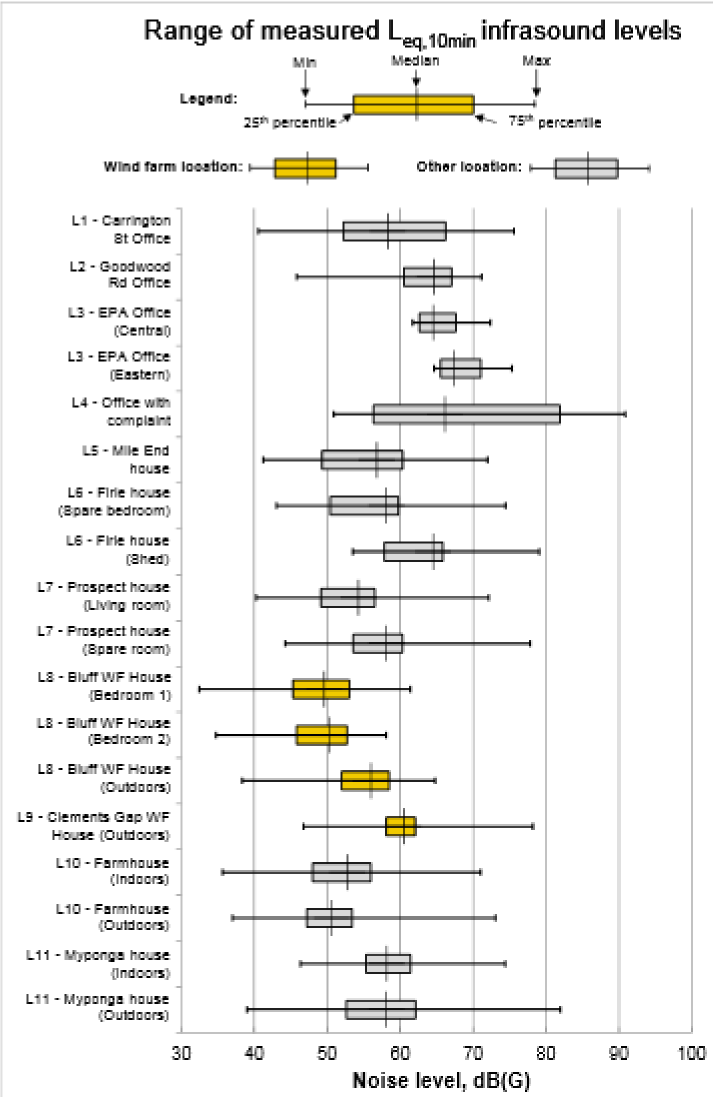
The Environmental Agency of North Rhein-Westphalia (LNW 2002) provided some data on SPLs by distance from a single wind turbine with a sound power level of 103 dB(A). Details as reproduced by Ellenbogen et al. (2012) are as follows:

- At a distance of 280 m from the turbine, the SPL corresponds to 45 dB(A).
- At a distance of 410 m from the turbine, the SPL corresponds to 40 dB(A).
- At a distance of 620 m from the turbine, the SPL corresponds to 35 dB(A).

### *Turbine sound in the national setting*

A recent study by the Environment Protection Authority in South Australia (Evans, Cooper & Lenchine 2013) examined the level of infrasound within typical environments in South Australia. The key objective of the study was to compare two wind farm environments with urban (seven locations) and rural (four locations) environments away from wind farms. Both indoor and outdoor measurements were undertaken over a period of approximately 1 week at specified locations. Levels of background noise were also measured at residences approximately 1.5 km from the wind farms during organised shutdowns of the turbines.

Figure 4 summarises the range of measured $L_{eq,\ 10\ minutes}$ (equivalent noise level over a 10-minute measurement period) infrasound levels at each of the measurement locations in the study.




Source: Figure 1, p. iv of Evans, Cooper and Lenchine (2013)

## Figure 4 Range of measured $L_{eq,\ 10\ minutes}$ infrasound levels at each measurement location

The study concluded that the level of infrasound at locations near wind turbines was no greater than that experienced in other urban and rural environments. The study also found that the contribution of wind turbines to the measured infrasound levels was insignificant in comparison with the background level of infrasound in the environment. The report noted the following:

- For the rural environments:
  - Outdoor infrasound levels were similar to, or marginally above, indoor infrasound levels.
  - Infrasound levels at houses near wind farms were not higher than those at houses located at significant distances from wind farms (e.g., the outdoor infrasound levels at one location 1.5 km from an operational wind farm were ‘significantly’ lower than those at another location at a distance of 30 km). Results at one of the locations near a wind farm were the lowest infrasound levels measured at any of the locations included in the study.

    - Infrasound levels in the rural environment appear to be controlled by localised wind conditions where, during low wind periods, levels as low as 40 dB(G) were measured at locations both near and away from wind turbines. At higher wind speeds, infrasound levels of 50 –70 dB(G) were common at both wind farm and non-wind-farm sites.
- For the urban environments:
    - Infrasound levels of between 60 and 70 dB(G) commonly occur in the urban environment (levels were typically 5–10 dB(G) higher during the day than at night).
    - Noise generated by people and associated activities within a space was one of the most significant contributors to measured infrasound levels, which were typically 10–15 dB(G) higher when a space was occupied. Infrasound levels up to approximately 70 dB(G) were measured in occupied spaces.
    - Traffic influenced the infrasound level in an urban environment, with measured levels during daytime periods typically 10 dB(G) higher than between midnight and 6 am, when traffic activity is likely to be at its lowest.
    - At two locations, including a site with a low-frequency noise complaint, building air conditioning systems were identified as significant sources of infrasound (some of the highest levels of infrasound measured during the study were exhibited at these sites).

Overall, measured G-weighted infrasound levels at rural locations both near and away from wind farms were no higher than infrasound levels measured at the urban locations. Both outdoor and indoor infrasound levels were well below the perception threshold, and the most apparent difference between the urban and rural locations was that human/traffic activity appeared to be the primary source of infrasound in urban locations, while localised wind conditions were the primary source of infrasound in rural locations.

*Wind farm noise limits in Australia*

New South Wales, South Australia, Tasmania, Victoria and Western Australia all have general noise limits applicable to wind turbines (Table 10).

### Table 10 Australian state and territory noise level limits

| State/territory | Guidance document for assessment | Minimum noise level limit[a] | Penalty for noise characteristics | Comments |
|---|---|---|---|---|
| ACT | - | - | - | Wind farm guidance has not been prepared. |
| New South Wales | South Australia Environment Protection Authority (EPA) *Environmental noise guidelines: Wind farms*, 2003 | $LA_{eq,\ 10\ minutes}$ 35 dB | 5 dB | Penalty applies for tonality only. No other characteristics are assessed directly. |
| Northern Territory | - | - | - | There is no specific wind farm assessment document. Developments would likely be assessed on a case-by-case basis. |
| Queensland | - | - | - | There is no specific guidance regarding wind farms. Developments would likely be assessed on a case-by-case basis. NZS6808: 1998 and South Australia EPA Guidelines 2003 have been referred to previously. |
| South Australia | South Australia Environment Protection Authority *Wind farms environmental guidelines* 2009 | $LA_{90}$ 35–40 dB | 5 dB | Penalty applies for tonality only. No other characteristics are assessed directly. |
| Tasmania | Department of Primary Industries, | - | 5 dB | General guidance on the assessment of wind farm noise emission is provided in the TNMP, |

| State/territory | Guidance document for assessment | Minimum noise level limit[a] | Penalty for noise characteristics | Comments |
|---|---|---|---|---|
| | Water and Environment (Tasmania), *Noise Measurement Procedures Manual*, 2004 (TNMP) | | | but limits are not explicitly stated and would likely be assessed on a case-by-case basis.<br>A 5 dB penalty applies for one characteristic. The maximum penalty is 10 dB. Amplitude modulations, impulsiveness, low-frequency noise and tonality are considered. |
| Victoria | New Zealand Standard NZ 6808: 1998 *Acoustics – the assessment and measurement of sound from wind turbine generators* | $LA_{95}$ 40 dB | 5 dB | - |
| Western Australia | *Environmental Protection (Noise) Regulations 1997*. Guidance for the Assessment of Environmental Factors No. 8 – Environmental Noise, s3.2.2 (draft, May 2007) | - | The WA noise regulations specify adjustments of 5 dB for tonality and modulation and 10 dB for impulsiveness to be added to the $LA_{Slow}$ level, to a maximum of 15 dB. | Additionally, the Western Australian government document, *Guidelines for wind farm development*, suggests that turbines are set back at least 1 km. |

Note: Where minimum noise level limits have been established in a state or territory, it has generally been in conjunction with a variation of the limit in periods of high background noise.

Source: EPHC (2010)

## Systematic literature review

### *SQ1. IS THERE ANY RELIABLE EVIDENCE OF AN ASSOCIATION BETWEEN DISTANCE FROM WIND TURBINES AND ADVERSE HEALTH EFFECTS?*

### *SQ2. IS THERE ANY RELIABLE EVIDENCE OF AN ASSOCIATION BETWEEN AUDIBLE NOISE (GREATER THAN 20 HZ) FROM WIND TURBINES AND ADVERSE HEALTH EFFECTS?*

Seven cross-sectional studies (discussed in 11 articles) (level IV aetiology evidence) reported on the health effects of wind turbine noise exposure. Five of the studies could be clearly defined as reporting noise exposure within the audible range on the basis of reporting estimates of exposure in dB(A); the remaining two studies have been included in the analysis even though they report only distance from a wind turbine or wind farm, because distance from wind turbines can be considered to be a surrogate for sound pressure level (SPL).

A profile of each study is given in Table 7 (page 46), along with a consideration as to how bias, confounding and chance may have affected the validity of the results produced. Detailed study profiles are given in APPENDIX B.

Members of one research group were involved in the conduct of three of the included studies (SWE-00, SWE-05, NL-07) that are discussed in six articles (Bakker et al. 2012; Pedersen 2011; Pedersen & Larsman 2008; Pedersen et al. 2009; Pedersen & Persson Waye 2004, 2007).

Results of all the studies are presented according to the different effects measured, including self-reported health effects (i.e. physical and mental health); and other health-related effects such as quality of life, sleep quality and sleep disturbance. Data on health-related effects were extracted because they can be related to stress, which is a possible mediator or moderator of health outcomes. Data on the association between annoyance and health outcomes within populations exposed to different levels of noise exposure (sound levels or distance from wind turbines) were also extracted.

### Association between wind turbine noise and physical health effects

Six studies reported on the association between estimated sound pressure from wind turbines and self-reported physical health effects (studies SWE-00, SWE-05 and NL-07; see Table 11, as reported in the re-analysis of these data by Pedersen (2011)) or distance from wind turbines and self-reported health outcomes (Krogh et al. 2011; Nissenbaum, Aramini & Hanning 2012; Shepherd et al. 2011; see Table 12). A publication on study NL-07 examined possible independent predictors for each of the health outcomes (van den Berg et al. 2008) (see Table 13). Each of the six studies adjusted for different plausible confounders, some to a greater extent than others, but all still had the potential for confounded results (see Table 7, page 46).

Pedersen (2011) contrasted health outcome data from three studies that the author had been involved in, in a re-analysis. The results from the two Scandinavian studies (SWE-00 and SWE-05) and the Dutch study (NL-07), presented in the form of odds ratios (OR) and their 95% confidence intervals (95% CIs), are shown in Table 11. An OR above 1.00 suggests that there is a positive association between the dependent variable (in this case a health condition) and the independent variable (e.g. estimated SPL); that is, the frequency of the health condition increases as the SPL increases. An OR below 1.00 suggests the opposite. The 95% CI indicates the extent of uncertainty in the OR. Thus, for example, if an OR is above 1.00 but its lower 95% CI bound is below 1.00, there might be no association between the health condition and SPL, or the frequency of the health condition might even be reduced with increasing sound pressure.

Only one of the self-reported health conditions investigated in studies SWE-00, SWE-05 and NL-07, tinnitus, had an OR that was above 1.00 and a lower confidence bound that was greater than 1.00. This association between self-reported tinnitus and SPL was observed only in SWE-00 (Pedersen & Persson Waye 2004) and was not replicated in either SWE-05 or NL-07. Similarly, the weak evidence (trend) of a positive association between SPL and prevalence of self-reported diabetes in SWE-05 (Pedersen & Persson Waye 2007) was not replicated in SWE-00 or NL-07. In these single studies the analyses had all been adjusted for age and gender; however, NL-07 also adjusted for economic benefit (see page 77). Overall, physical health (as measured using slightly different tools) did not appear to vary with estimated level of exposure to noise or distance from wind turbines.

When there are multiple comparisons conducted using statistical analysis, there is always the possibility that a statistically significant association may occur by chance. If a p value of 0.05 is used, when 20 statistical tests are performed in the one study it is likely that one statistically significant result will be spurious. One method of dealing with this is to use the Bonferroni correction, which adjusts the p value for the number of comparisons made. The original (2004) publication of SWE-00 used a Bonferroni correction in the statistical analysis, although it did not present any health outcome data. It is unclear whether the re-analysis of the SWE-00 data in Pedersen (2011), which analysed self-reported health effects across SWE-00, SWE-05 and NL-07, included a Bonferroni correction, as it is not mentioned. However, the concept of multiple statistical tests causing spurious associations is mentioned in Pedersen (2011) and, appropriately, the author only considered associations to be meaningful when they were consistently present across all three studies.

Table 11 Association between estimated A-weighted sound pressure levels from wind turbines and specific physical health effects (OR, 95%CI)

| Study | Self-reported health outcome | SWE-00[a] N[c]=319–333 | SWE-05[a] N[c]=720–744 | NL-07[b] N[c]=639–678 |
|---|---|---|---|---|
| Comparison of studies NL-07, SWE-00 and SWE-05 Pedersen (2011) | Chronic disease | 0.97 (0.89, 1.05) | 1.01 (0.96, 1.07) | 0.98 (0.95, 1.01) |
| | Diabetes | 0.96 (0.79, 1.16) | 1.13 (1.00, 1.27) | 1.00 (0.92, 1.03) |
| | High blood pressure | 1.03 (0.90, 1.17) | 1.05 (0.97, 1.13) | 1.01 (0.96, 1.06) |
| | Cardiovascular disease | 0.87 (0.68, 1.10) | 1.00 (0.88, 1.13) | 0.98 (0.91, 1.05) |
| | Tinnitus | **1.25 (1.03, 1.50)** | 0.97 (0.88, 1.07) | 0.94 (0.85, 1.04) |
| | Impaired hearing | 1.09 (0.93, 1.27) | 1.05 (0.95, 1.15) | 1.01 (0.94, 1.10) |
| | Headache | 0.95 (0.88, 1.02) | 1.04 (0.99, 1.10) | 1.01 (0.98, 1.04) |

**Bolded values indicate statistically significant differences.**
Abbreviations: OR = odds ratio; CI = confidence interval
[a] Adjusted for age and gender.
[b] Adjusted for age, gender and economic benefits.
[c] Range of number of respondents in the analyses. Differences in number of respondents are due to respondents not answering some individual questions in the questionnaire.

Similar to the results of the three studies above, Shepherd et al. (2011), Krogh et al. (2011) and Nissenbaum, Aramini and Hanning (2012) assessed whether respondents living closer to wind turbines had any more physical health complaints than those who were living further away, with the understanding that distance from a wind turbine is a proxy for the level of noise exposure from the turbine (Table 12).

Krogh et al. (2011) noted that a greater percentage of respondents living close to wind turbines reported altered health, headaches, migraines, hearing problems and tinnitus than those living further away from wind turbines, but the differences were not statistically significant. The rates of health complaints were high across both distance groups, which is probably a result of biased selection. Study locations were chosen specifically because adverse health effects had been anecdotally reported, and those with health complaints would probably be more likely to respond to the survey, given the lack of masking of study intent.

Although all the studies were of poor quality, one strength of both Shepherd et al. (2011) and Nissenbaum, Aramini and Hanning (2012) was the use of validated questionnaires to measure self-reported physical health. Shepherd et al. (2011) assessed general health with a single item in an abbreviated version of the World Health Organization Quality of Life questionnaire (WHOQOL-

BREF), while Nissenbaum, Aramini and Hanning (2012) measured physical health status using the Physical Component Summary Scale of version 2 of the Short Form-36 item questionnaire. Krogh et al. (2011) assessed general health with an author-developed non-standardised survey. Despite these differences, none of the studies reported any statistically significant associations between distance from wind turbines and self-reported physical health status over the different distances measured (Table 12).

Table 12 Association between distance from wind turbines (m) and physical health outcomes

| **Study** | **Self-reported health outcome** | **Proportion affected at distance (m) from nearest industrial wind turbine** | | **P value** |
|---|---|---|---|---|
| Shepherd et al. (2011) New Zealand N=198 | | **<2000 n=39** | **>8000 n=158** | |
| | WHOQOL-BREF self-rated general health | Not stated | Not stated | *t*(195) = 0.37, p=0.71 |
| Krogh et al. (2011)[a] Canada N=109 | | **350–673** (mean = 506) **n=not stated** | **700–2400** (mean = 908) **n=not stated** | |
| | Altered health | 94% | 85% | 0.19 |
| | Headaches | 70% | 53% | 0.10 |
| | Migraines | 18% | 9% | 0.24 |
| | Hearing problems | 38% | 32% | 0.67 |
| | Tinnitus | 60% | 51% | 0.42 |
| | Heart palpitations | 32% | 36% | 0.68 |
| | Approached doctor | 38% | 38% | 1.00 |
| Nissenbaum, Aramini and Hanning (2012) USA N=79 | | **350–673** (mean = 506) **n=not stated** | **700–2400** (mean = 908) **n=not stated** | |
| | Mean SF-36v2[b] Physical Component Score | Not stated | Not stated | 0.99 |

[a] Statistical analyses performed by Fisher's exact test. Age and gender were included in the model if significant at p<0.05.

[b] SF-36v2 = version 2 of the Short Form 36 item questionnaire.

### *SQ1, SQ2/BQ6. IS THERE EVIDENCE THAT THERE ARE CONFOUNDING FACTORS OR EFFECT MODIFIERS THAT MIGHT EXPLAIN THE ASSOCIATION OF WIND TURBINES WITH ADVERSE HEALTH EFFECTS?*

When van den Berg et al. (2008) assessed the results of NL-07 in detail (Table 13), age was found to be associated with self-reported chronic disease, diabetes, high blood pressure and cardiovascular disease (i.e. the older the respondent, the more likely they were to have reported symptoms), while gender was associated with migraine (females were more likely to report migraines than males). Thus, if either of these confounders were differentially distributed among residents living either near or far from a wind farm or in different SPL exposure groups, it might explain the associations between wind farms and the odd health effect that is observed in some studies. In Pedersen's re-analysis (Pedersen 2011), NL-07 study results were adjusted for age, gender and economic benefit and found no association between estimated SPLs and health complaints (Table 11). SWE-00 (and SWE-05) only adjusted for age and gender and found an association with tinnitus. Table 7 (page 46) provides additional information on plausible confounders that were not addressed in all 3 studies.

Shepherd et al. (2011) did not report adjusting for potentially confounding factors such as age, gender, economic benefits or predisposing health complaints. Krogh et al. (2011) mentioned that they would have adjusted for age and gender, had the univariate results been statistically significant.

Table 13 Estimated A-weighted sound pressure levels, age, gender and economic benefit, as possible independent predictors of health outcomes in multivariate models analysed in the Dutch study (NL-07)

| Study | Self-reported health outcome | Independent variables in multivariate model | Association of independent variable with health outcome OR (95%CI) |
|---|---|---|---|
| NL-07 Van den Berg et al. (2008) The Netherlands | Chronic disease | Sound levels | 0.98 (0.95, 1.01) |
| | | Economic benefits (no; yes) | 0.70 (0.35, 1.43) |
| | | Age (years) | **1.03 (1.01, 1.04)** |
| | | Gender (male; female) | 1.18 (0.82, 1.70) |
| | Diabetes | Sound levels | 1.00 (0.92, 1.09) |
| | | Economic benefits (no; yes)[a] | NC |
| | | Age (years) | **1.07 (1.03, 1.11)** |
| | | Gender (male; female) | 0.69 (0.28, 1.70) |
| | High blood pressure | Sound levels | 1.01 (0.96, 1.06) |
| | | Economic benefits (no; yes) | 0.15 (0.02, 1.20) |
| | | Age (years) | **1.06 (1.04, 1.08)** |

| Study | Self-reported health outcome | Independent variables in multivariate model | Association of independent variable with health outcome OR (95%CI) |
|---|---|---|---|
| | | Gender (male; female) | 1.27 (0.96, 1.06) |
| | Tinnitus | Sound levels | 0.94 (0.85, 1.04) |
| | | Economic benefits (no; yes) | 0.90 (0.10, 8.42) |
| | | Age (years) | 1.03 (0.99, 1.06) |
| | | Gender (male; female) | 1.26 (0.05, 3.36) |
| | Hearing impairment | Sound levels | 1.01 (0.94, 1.10) |
| | | Economic benefits (no; yes) | 0.38 (0.04, 3.31) |
| | | Age (years) | **1.05 (1.03, 1.10)** |
| | | Gender (male; female) | 0.60 (0.26, 1.37) |
| | Cardiovascular disease | Sound levels | 0.98 (0.91, 1.05) |
| | | Economic benefits (no; yes) | 0.39 (0.05, 3.26) |
| | | Age (years) | **1.06 (1.03, 1.09)** |
| | | Gender (male; female) | 0.61 (0.29, 1.27) |
| | Migraine | Sound levels | 0.93 (0.83, 1.04) |
| | | Economic benefits (no; yes)[a] | NC |
| | | Age (years) | 0.98 (0.94, 1.01) |
| | | Gender (male; female) | **13.2 (1.70, 101.86)** |

**Bolded values indicate statistically significant differences.**
Abbreviations: OR = odds ratio; CI = confidence interval; NC = not calculable
[a] No respondents who benefited economically had reported this chronic disease or any symptoms.

### Association between wind turbine noise and mental health effects

Five studies assessed the relationship between modelled A-weighted sound pressure and psychological distress (SWE-00, SWE-05 and NL-07), or distance from a wind turbine (as a proxy for noise exposure) and mental health (Krogh et al. 2011; Nissenbaum, Aramini & Hanning 2012). A higher estimated exposure to wind turbines (in this case, dwelling at a closer distance) was associated with poorer self-reported mental health in one of the five studies (Nissenbaum, Aramini & Hanning 2012).

It is unclear what tools were used to determine whether respondents were tense and stressed or irritable in the two Swedish studies (SWE-00 and SWE-05). The results of these two studies were consistent with NL-07 in not observing an association between SPL and being tense and stressed or irritable (Table 14).

Van den Berg et al. (2008) was explicit that study NL-07 measured psychological distress by the General Health Questionnaire (GHQ), with a scale ranging from 0 to 12. The variable was dichotomised into 'not psychologically distressed' and 'psychologically distressed' using a cut-off of 2 or above for the latter. However, stress scores were calculated from 13 items, with a 4-point scale from '(almost) never' to '(almost) daily', with response factors analysed so that the mean value was 0 and the standard deviation was 1. Six items were used to describe the symptoms of stress: feeling tense or stressed, feeling irritable, having mood changes, being depressed, suffering from undue tiredness and having concentration problems. Levels of A-weighted sound pressure were not associated with psychological distress or stress scores when other factors such as economic benefits, age and gender were taken into account (Table 15).

### Table 14 Association between estimated A-weighted sound pressure levels and stress

| **Study** | **Self-reported outcome** | **SWE-00[a]** **OR (95%CI)** N[c]=319–333 | **SWE-05[a]** **OR (95%CI)** N[c]=720–744 | **NL-07[b]** **OR (95%CI)** N[c]=639–678 |
|---|---|---|---|---|
| Comparison of studies NL-07, SWE-00 and SWE-05 Pedersen (2011) | Tense and stressed | 1.02 (0.94, 1.10) | 1.00 (0.95, 1.05) | 1.01 (0.98, 1.04) |
| | Irritable | 1.03 (0.96, 1.11) | 1.00 (0.96, 1.06) | 1.01 (0.98, 1.04) |

Abbreviations: OR = odds ratio; CI = confidence interval
[a] Adjusted for age and gender.
[b] Adjusted for age, gender, and economic benefits.
[c] Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases; that is, the respondents not answering single questions in the questionnaire.

Table 15 Relationship between estimated A-weighted sound pressure levels, other possible confounding factors and psychological distress or stress in study NL-07

| **Study** | **Self-reported health outcome** | **Independent variables in multivariate model** | **Association of independent variables with health outcome OR (95%CI)** |
|---|---|---|---|
| NL-07 Van den Berg et al. (2008) The Netherlands | Psychological distress on GHQ (<2; >2) (n=656) | Sound levels | 1.02 (0.99, 1.06) |
| | | Economic benefits (no; yes) | 0.74 (0.41, 1.34) |
| | | Age (years) | 0.99 (0.99, 1.00) |
| | | Gender (male; female) | 1.12 (0.78, 1.58) |
| | Stress scores (<0; ≥0.01) (n=656) | Sound levels | 1.01 (0.98, 1.04) |
| | | Economic benefits (no; yes) | 0.61 (0.35, 1.07) |
| | | Age (years) | **0.98 (0.97, 0.99)** |
| | | Gender (male; female) | 1.32 (0.83, 1.64) |

**Bolded values indicate statistically significant differences.**
Abbreviations: OR = odds ratio; CI = confidence interval

Two studies assessed the relationship between distance from wind turbines and mental health (Table 16). Nissenbaum and colleagues (2012) used the Mental Component Summary Scale of the Short Form-36 item questionnaire (version 2), a validated instrument, but did not control for all plausible confounders (see Table 7, page 46). They found that the mental health scores of residents living either near wind farms or further away were both within the normal range (population norm, mean = 50, SD = 10), although the mean value indicated poorer mental health for residents living near wind farms (p=0.002). Participants were not masked to the intent of the study and so it likely that recall bias may also have influenced the findings. Nissenbaum and colleagues also found that participants living close to a wind turbine (375–1400 m) were much more likely to self-report a new diagnosis of depression or anxiety since the introduction of the wind turbines than the 'far' group (living over 3 km from a wind turbine). Similarly, participants in the 'near' group reported a greater amount of new psychotropic medication being taken than those in the 'far' group, although the difference was not statistically significant.

Krogh et al. (2011), using a purpose-designed questionnaire, did not detect any significant differences in the rates of self-reported stress, anxiety or depression. The difference between these results and those reported by Nissenbaum, Aramini and Hanning (2012) could be due to various factors including sample selection, the impact of plausible confounders (see Table 7, page 46), measurement tool/question used, and difference in residential distance from turbines.

### Table 16 Relationship between distance and self-reported mental health

| Study | Self-reported health outcome | Proportion affected at distance (m) from nearest industrial wind turbine | | P value |
|---|---|---|---|---|
| Krogh et al. (2011) Canada N=109 | | **350–673** (mean = 506) **n=not stated** | **700–2400** (mean = 908) **n=not stated** | |
| | Stress | 66% | 72% | 0.52 |
| | Anxiety | 54% | 49% | 0.69 |
| | Depression | 46% | 36% | 0.41 |
| | Distress (if at least one of stress, anxiety or depression were reported as 'yes') | 68% | 77% | 0.37 |
| Nissenbaum, Aramini and Hanning (2012) USA N=79 | | **375–1400** (mean = 792) **n=38** | **3000–6600** (mean = 5248) **n=41** | |
| | New diagnosis of depression or anxiety | 9/38 (23.6%) | 0/41 (0%) | Not stated |
| | New psychotropic medication | 9/38 (23.6%) | 3/41 (7.3%) | 0.06 |
| | Mean SF36v2[a] Mental Component Score | 42.0 | 52.9 | **p=0.002** |

[a] SF-36v2 = version 2 of the Short Form 36 item questionnaire.

## Association between wind turbine noise and quality of life

Three studies reported on the association between distance from wind turbines and quality of life (QoL) (Krogh et al. 2011; Nissenbaum, Aramini & Hanning 2012; Shepherd et al. 2011); the results of the studies are shown in Table 17.

Shepherd et al. (2011) compared QoL in respondents who lived less than 2 km or greater than 8 km from a wind turbine. This cross-sectional study attempted to mask the intent of the study by asking about annoyance from traffic noise, neighbours or 'other noise (please specify)'. Overall QoL was assessed using a single question in the abbreviated World Health Organization Quality of Life questionnaire (WHOQOL-BREF). This questionnaire was also used by the authors for measurements on several domains, including physical (7 items), psychological (6 items), environmental (8 items) and social (3 items) QoL. Shepherd et al. (2011) found that those living nearer to wind turbines had significantly lower scores than those who lived further away, in the domains of physical ($F(1,194)$ = 5.816, p=0.017), environmental ($F(1,194)$=5.694, p=0.018) and mean self-rated overall QoL ($t$(195)=2.364, p=0.019), as well as on an additional amenity-rating question added by the authors ($F$(1,194)=18.88, p<0.001). The absolute difference in QoL between the groups for each domain was less than 10%. Perceived sleep quality was one facet of the physical domain that showed a difference between the groups ($t$(195)=3.089, p=0.0006), as did self-reported energy levels ($t$(195)=2.217, p=0.028), but the absolute differences between groups in these aspects of QoL were not reported. Psychological and social domains did not show any significant differences between the groups. Results were not adjusted for all plausible confounders (Table 7, page 46).

Krogh et al. (2011) only included people in their study who lived less than 2400 m from a wind turbine, and nearly all respondents (96–98%) answered 'yes' to the non-masked survey question 'Do you feel that your quality of life has in any way altered since living near wind turbines?'

Nissenbaum, Aramini and Hanning (2012) asked respondents whether they wished to move away. The majority of those living less than 1.4 km from a wind turbine responded in the affirmative (74%), whereas none of the group who lived over 3 km from a wind turbine wished to move.

Table 17 Association between distance from a wind turbine and quality of life

| Study | Self-reported outcome measure | Mean scores or proportion affected at distance (m) from nearest industrial wind turbine | | Statistic | p value |
|---|---|---|---|---|---|
| Shepherd et al. (2011) New Zealand N=198 | | **<2000 n=39** | **>8000 n=158** | | |
| | Psychological domain[a] | 22.36±2.67 | 23.29±2.91 | $F$(1,194)=3.33 | p=0.069 |
| | Physical domain[a] | 27.38±3.14 | 29.14±3.89 | $F$(1,194)= 5.82 | **p=0.017** |
| | Self-reported energy levels | Not stated | Not stated | $t$(195)=2.2 | **p=0.028** |
| | Perceived sleep quality[a] | Not stated | Not stated | $t$(195)=3.09 | **p=0.0006** |
| | Social domain[a] | 12.53±1.83 | 12.54±2.13 | $F$(1,194)=0.002 | p=0.96 |
| | Environmental domain[a] | 29.92±3.76 | 32.76±4.41 | $F$(1,194)=5.69 | **p=0.018** |
| | Amenity | 7.46±1.42 | 8.91±2.64 | $F$(1,194)=18.88 | **p<0.001** |
| | WHOQOL-BREF overall quality of life | Not stated | Not stated | $t$(195)=2.36 | **p=0.019** |

| Study | Self-reported outcome measure | Mean scores or proportion affected at distance (m) from nearest industrial wind turbine | | Statistic | p value |
|---|---|---|---|---|---|
| Krogh et al. (2011) Canada N=109 | | **350–673** (mean = 506) **n=not stated** | **700–2400** (mean = 908) **n=not stated** | | |
| | Altered quality of life | 96% | 98% | | p=1.00 |
| Nissenbaum, Aramini and Hanning (2012) USA N=79 | | **375–1400** (mean = 792) **n=38** | **3000–6600** (mean = 5248) **n=41** | | |
| | Wishing to move away | 73.7% | 0% | | **p<0.001** |

**Bolded values indicate statistically significant differences.**

[a] Mean ± standard deviation. A high score indicates better QoL. The WHOQOL-BREF psychological domain has a maximum score of 30, the physical domain has a maximum score of 35, and the social domain has a maximum score of 15, while the environmental domain has a maximum score of 40. The raw domain scores do not appear to have been transformed to a 0–100 scale.

## Other relevant outcomes

### *Association between wind turbine noise and sleep disturbance*

All seven studies assessed the association between estimated wind turbine noise and sleep disturbance or sleep quality. Three studies assessed the association between sleep and estimated A-weighted SPL (SWE-00, SWE-05, NL-07), while the four remaining studies assessed the relationship between distance from a wind turbine and sleep quality. Only subjective sleep measures were used. There were no studies that measured sleep objectively.

One article (Pedersen 2011) summarised the two Scandinavian studies and the one Dutch study (SWE-00, SWE-05 and NL-07), and reported that there was an association between estimated A-weighted SPL and the frequency of sleep disturbance in one of the studies, as determined subjectively by the respondents ('(almost) never', 'at least once a year', 'at least once a month', 'at least once a week', and '(almost) daily'). A minimum of at least once a month was considered to be sleep disturbance. The results are shown in Table 18. The first Swedish study (SWE-00) reported that increases in estimated SPL increased the odds of having sleep interruption due to estimated wind turbine noise. Results were similar in the Dutch study, where a trend was observed. The second Swedish study (SWE-05), carried out in more densely populated areas, did not report a statistically significant association between estimated SPL and sleep disturbance. Pedersen hypothesised that a combination of lowered expectations of quietness and higher levels of background noise could have explained this lack of association (Pedersen 2011).

Pedersen and Persson Waye (2004) reported from study SWE-05 that 23% of respondents had stated that their sleep was disturbed by noise from road traffic, rail traffic, neighbours or wind turbines. At lower estimated exposure to noise from wind turbines, no respondents reported sleep disturbance, whereas 16% of the respondents exposed to sound over 35 dB(A) reported disturbed sleep. Of these, 18/20 reported sleeping with an open window in the summer. In the Dutch sample (study NL-07), described in van den Berg et al. 2008, 30% of respondents reported difficulties in falling asleep at least once a month, while 25% reported interrupted sleep at least once a month. Paradoxically, those exposed to the greatest estimated A-weighted SPLs from wind turbines had the least difficulty falling asleep, while those exposed to the least A-weighted SPLs had the most difficulty falling asleep. However, this trend largely disappeared when adjusted for possible confounding by age, gender and economic benefit (Table 19).

The association of estimated *SPL* on sleep interruption in the SWE-00, SWE-05 and NL-07 studies was not as strong as the association of wind turbine noise *annoyance* with sleep interruption (see Table 26).

### Table 18 Association between estimated A-weighted sound pressure levels and sleep disturbance (OR, 95%CI)

| **Study** | **Self-reported outcome** | **SWE-00[a]**<br>**OR (95%CI)**<br>N[c]=319–333 | **SWE-05[a]**<br>**OR (95%CI)**<br>N[c]=720–744 | **NL-07**<br>**OR (95%CI) or %**<br>N[c]=639–678 |
|---|---|---|---|---|
| Comparison of studies NL-07, SWE-00 and SWE-05<br>Pedersen (2011) | Sleep interruption | **1.12 (1.03, 1.22)** | 0.97 (0.90, 1.05) | 1.03[b] (1.00, 1.07) |
| | Undue tiredness | 0.95 (0.88, 1.02) | 0.98 (0.93, 1.03) | 1.02[b] (0.99, 1.05) |
| NL-07<br>Van den Berg et al. (2008)<br>The Netherlands | Difficulties in falling asleep | - | - | N=710<br><30 dB(A): 36%<br>30–35 dB(A): 31%<br>35–40 dB(A): 28%<br>40–45 dB(A): 32%<br>>45 dB(A): 16% |
| | Sleep interruption | - | - | N=718<br><30 dB(A): 21%<br>30–35 dB(A): 26%<br>35–40 dB(A): 26%<br>40–45 dB(A): 26%<br>>45 dB(A): 28% |

**Bolded values indicate statistically significant differences.**
Abbreviations: OR = odds ratio; CI = confidence interval
[a] Adjusted for age and gender.

[b] Adjusted for age, gender, and economic benefits.
[c] Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases, that is, the respondents not answering single questions in the questionnaire.

*BQ6. Is there evidence that there are confounding factors or effect modifiers that might explain the association of wind turbines with sleep disturbance?*

Van den Berg et al. (2008) assessed the odds of respondents in NL-07 reporting difficulties falling asleep, or interrupted sleep, at least once a month with increasing SPL, while simultaneously controlling for other factors including economic benefits, age and gender (Table 19). They reported that difficulty falling asleep was positively correlated with age ($r_s$=0.08, n=691, p<0.05), with older respondents having more difficulty falling asleep. Conversely, having interrupted sleep was negatively correlated with age, with younger participants having more interrupted sleep ($r_s$=-0.08, n=699, p<0.05). Females more often had problems falling asleep than males, and those who did not economically benefit from wind turbines or were older tended to have more trouble falling asleep than others. Respondents who benefited economically were less likely to report having had interrupted sleep. Sound level was the only factor that was not statistically significant at predicting the likelihood of falling asleep. An increase in sound level was associated with a trend towards a small increase in risk of having interrupted sleep. Thus, the impact of confounders might explain the difference in results between NL-07 and SWE-00; the former study adjusted for economic benefits while the latter did not.

Table 19 Relationship between estimated A-weighted sound pressure levels, other possible confounding factors and sleep quality in study NL-07

| Study | Self-reported outcome | Independent variables | Results OR (95%CI) |
|---|---|---|---|
| NL-07 (Van den Berg et al. 2008) The Netherlands | Falling asleep | Sound levels | 0.99 (0.97, 1.03) |
| | | Economic benefits (no; yes) | **0.52 (0.27, 0.97)** |
| | | Age (years) | **1.02 (1.01, 1.03)** |
| | | Gender (male; female) | **1.47 (1.05, 1.06)**[a] |
| | Interrupted sleep | Sound levels | 1.03 (1.00, 1.07) |
| | | Economic benefits (no; yes) | **0.45 (0.24, 0.84)** |
| | | Age (years) | 1.00 (0.99, 1.01) |
| | | Gender (male; female) | 1.07 (0.75, 1.51) |

**Bolded values indicate statistically significant differences.**
Abbreviations: OR = odds ratio; CI = confidence interval
[a] Confidence interval incorrectly reported in article.

### *Association between wind turbine noise and sleep quality*

All four studies that compared sleep quality in respondents living close to wind turbines, compared with further away, found at least one sleep-related outcome that was statistically significantly different between groups (3 studies) or trending that way (1 study). Results were not adjusted for all plausible confounders (Table 7, page 46). Some outcome measures were not statistically significant but still reported trends towards worse sleep in respondents who lived closer to wind turbines. The results are shown in Table 20.

Table 20 Association between sleep quality and distance from nearest wind turbine

| Study | Self-reported outcome | Distance (m) from nearest industrial wind turbine | | Difference |
|---|---|---|---|---|
| Shepherd et al. (2011) New Zealand N=197 | | **<2000 n=39** | **>8000 n=158** | **(statistical tests and p values)** |
| | Perceived sleep quality | % not stated | % not stated | *t*(195)=3.089, **p=0.006** |
| Krogh et al. (2011) Canada N=109 | | **350–673** (mean = 506) **n=not stated** | **700–2400** (mean = 908) **n=not stated** | **p value** |
| | Disturbed sleep | 78% | 60% | 0.078 |
| | Excessive tiredness | 86% | 66% | **0.031** |
| Morris (2012) Australia N=93 | | **0–5000 n=41** | **5000–10,000 n=52** | **OR (95%CI)** |
| | Disturbed sleep[a] | 16/41 (39.0%) | 11/52 (21.1%) | 2.39 (0.96, 5.95) |
| Nissenbaum, Aramini and Hanning (2012) USA N=79 | | **375–1400** (mean = 792) **n=38** | **3000–6600** (mean = 5248) **n=41** | **p value** |
| | PSQI mean score | 7.8 | 6.0 | **0.046** |
| | PSQI score >5[b] | 65.8% | 43.9% | 0.07 |
| | ESS mean score | 7.8 | 5.7 | **0.03** |
| | ESS score >10[c] | 23.7% | 9.8% | 0.13 |
| | Mean worsening sleep post WTs[d] | 3.1 | 1.3 | **<0.0001** |
| | Improved sleep when away from WTs | 14/28 (50%) | 2/34 (5.8%) | **<0.0001** |
| | Average new sleep medications post WTs | 13.2 | 7.3 | 0.47 |

| Study | Self-reported outcome | Distance (m) from nearest industrial wind turbine | | Difference |
|---|---|---|---|---|
| | New diagnoses of insomnia (n) | 2 | 0 | |

**Bolded values indicate statistically significant differences.**
Abbreviations: OR = odds ratio; CI = confidence interval; PSQI = Pittsburgh Sleep Quality Index; ESS = Epworth Sleepiness Scale; WTs = wind turbines
[a] Categorised on basis of reports such as cannot get to sleep; awaken; cannot return to sleep; wake in panic, sweat; wake due to ear pain, ear pressure, headache, nausea; had to move away; high blood pressure.
[b] PSQI >5 is considered a 'poor sleeper'.
[c] About 10–20% of general population has an ESS score >10.
[d] New sleep problems +worsening sleep problems/2; strongly agree (5) – strongly disagree (1).

Shepherd et al. (2011) reported that perceived sleep quality (one of the variables assessed in the WHOQOL-BREF questionnaire) was worse in respondents who lived within 2 km of a wind turbine, compared with respondents who lived at least 8 km from a wind turbine ($t(195)=3.09$, $p=0.006$). Although this result is statistically significant, it is unclear what it meant in absolute terms for the respondents, as actual scores were not provided. Krogh et al. (2011) and Morris (2012) both used investigator-developed questionnaires that had not been validated to ascertain levels of disturbed sleep, and reported higher rates of disturbed sleep in respondents who lived closer to wind turbines than further away. The difference in disturbed sleep was not statistically significant in Krogh et al. (2011) ($p=0.078$) but the difference in level of 'excessive tiredness' was. The Australian study by Morris provided sufficient detail to permit the reviewers to determine a non-significant trend suggesting that those who lived within 5 km of a wind turbine had higher odds of reporting disturbed sleep than those who lived between 5 and 10 km away (OR 2.39 95% CI 0.96, 5.95).

Nissenbaum, Aramini and Hanning (2012) reported statistically significantly worse sleep in those who lived closer to wind turbines (less than 1.4 km) than those who lived further away (3.0–6.6 km) for the majority of sleep outcomes. For sleep quality, as measured on the Pittsburgh Sleep Quality Index (PSQI)[32], mean scores were statistically higher in the group of respondents who lived closer to wind turbines. This corresponded to significantly worse sleep quality, sleep latency, sleep duration and habitual sleep efficiency; sleep disturbance; greater use of sleep medication; and more daytime dysfunction (Buysse et al. 1989). A score of over 5 on the PSQI is classified as a 'poor sleeper'. There were a higher percentage of respondents who met this classification in the 'near' group than the 'far' group, although the difference was not statistically significant. Both groups would be considered to have poor sleep quality.

In Nissenbaum, Aramini and Hanning's (2012) study, daytime sleepiness was measured by the Epworth Sleepiness Scale (ESS). The mean ESS in those closer to turbines was 7.8, compared with 5.7 for those further away ($p=0.03$). When the results were dichotomised to assess the percentage of those with a score of greater than 10, differences between the groups were not statistically

[32] The scale is 0–21, with 0 being best sleep quality and 21 being worst sleep quality, and a score of 5 and above is indicative of poor sleep quality.

significant, although the absolute difference between the groups was greater than 10% (Table 20). This result should be interpreted in the context of the ESS's usefulness as a measure of sleepiness. The ESS is a scale that measures the likelihood of falling asleep in eight different situations. It is used to detect subjective problematic sleepiness in patients with sleep disorders and is not highly correlated with objective markers of sleepiness. Normal ranges vary according to the population studied, but generally scores of <9 indicate the absence of problematic sleepiness. In most patients with insomnia disorders, the ESS score is similar to, or lower than, controls.

As well as using the validated instruments of the PSQI and ESS, Nissenbaum, Aramini and Hanning (2012) asked respondents in their questionnaire whether they considered that their sleep had worsened since the introduction of a wind turbine near their house, and whether they had improved sleep when away from wind turbines. Those living further away from the turbine, on average, disagreed that their sleep had worsened, while those living closer, on average, neither agreed nor disagreed. Half of the participants living within 1.4 km of a wind turbine reported improved sleep when away from turbines, compared with less than 6% in the group who lived over 3 km from a wind turbine. The difference was statistically significant.

### *Association between wind turbine noise and annoyance*

Four studies assessed levels of annoyance or disturbance due to wind turbine noise in groups of people exposed to different estimated SPLs and/or living at different distances from wind turbines. Although annoyance is not considered to be a health effect by itself (i.e. it is a response rather than an effect), it is associated with stress, which could be considered a mediator or a moderator of health outcomes or health-related effects. Conversely, those with impaired physical or mental health may be more vulnerable to annoyance (Laszlo et al. 2012). Pedersen, the author of the Scandinavian studies, describes being annoyed as having 'a lowered wellbeing', which 'should therefore be avoided' (Pedersen 2011).

The results of three studies (SWE-00, SWE-05 and NL-07) that reported on annoyance at wind turbine noise outdoors or indoors were combined in one publication (Pedersen 2011), and the results are shown in Table 21. Annoyance was treated as a binary outcome, with 'do not notice', 'notice but not annoyed' and 'slightly annoyed' responses combined and compared against responses of 'rather annoyed' and 'very annoyed'. All results shown were statistically significant, indicating that, at greater estimated A-weighted SPLs, respondents were more likely to report annoyance at wind turbine noise. However, in the Swedish study (SWE-05) estimated SPL was not an independent predictor of noise annoyance when analyses were controlled for visibility of wind turbines, background noise and/or area type (whether rural or urban, with complex or flat terrain) (Pedersen & Persson Waye 2007). Conversely, in the Dutch study (NL-07) reported by Pedersen et al. (2009), estimated SPL was observed to be associated with annoyance independently of economic benefit, visibility of wind turbines and area type (Table 24).

Table 21 Association between estimated A-weighted sound pressure levels (independent, continuous variables) and annoyance at wind turbine noise (OR, 95%CI)

| Study | Outcome measure | SWE-00[a] OR (95%CI) N[c]=319–333 | SWE-05[a] OR (95%CI) N[c]=720–744 | NL-07[b] OR (95%CI) N[c]=639–678 |
|---|---|---|---|---|
| Comparison of studies NL-07, SWE-00 and SWE-05 Pedersen (2011) The Netherlands and Sweden | Annoyance outdoors | **1.24 (1.13, 1.36)** | **1.14 (1.03, 1.27)** | **1.18 (1.12, 1.24)** |
| | Annoyance indoors | **1.38 (1.20, 1.57)** | **1.42 (1.17, 1.71)** | **1.20 (1.13, 1.27)** |

**Bolded values indicate statistically significant differences.**
Abbreviations: OR = odds ratio; CI = confidence interval
[a] Adjusted for age and gender.
[b] Adjusted for age, gender and economic benefits.
[c] Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases, that is, the respondents not answering single questions in the questionnaire.

Details of the rates of annoyance at wind turbine noise in SWE-00, SWE-05 and NL-07 are shown in Table 22. Pedersen and Persson Waye (2004) reported that, from study SWE-00, the relative odds of being annoyed by wind turbine noise was 1.9 per noise exposure category. The pseudo-$R^2$ was 0.13, suggesting that only 13% of the variance in annoyance could be explained by estimated A-weighted SPL (Table 22). In other words, estimated noise level was not a good predictor of annoyance.

In an unadjusted analysis Bakker et al. (2012) reported that, in a Dutch population (study NL-07), response to wind turbine sound outdoors was correlated with levels of wind turbine sound ($\rho$[33]=0.50, n=708, p<0.001), with the proportions of respondents annoyed by the sound increasing as sound levels increased, up to 45 dB(A), after which the proportions decreased. Similarly, perception and annoyance increased with increasing estimated SPLs indoors ($\rho$=0.36, n=699, p<0.001) (Pedersen et al. 2009).

One Australian study analysed results by distance from a wind turbine reported on annoyance or disturbance by wind turbine noise (Table 23). This study asked “does the wind farm generate noise disturbance?” (Morris 2012). The study had a low response rate (40%) (risk of sample selection bias) and no masking of study intent (risk of recall bias), meaning that people more likely to report disturbance could have been more interested in participating in the survey. Those living closer to wind turbines had much greater odds of being disturbed during the day and night by wind turbine noise than those who lived further away. The disturbances listed were specified as vibration of

[33] Spearman’s rho.

building, noise (roaring, thumping, grinding, whining, drumming, constant rumbling, noise that can be heard over the television) and changes in behaviour required (have to keep windows shut, had to relocate lounge room to hear television). No adjustments were made for potential confounding factors such as age, gender or economic benefits.

Overall, the results of the four studies were consistent in showing that, at closer distances or greater sound levels, respondents were more likely to report being annoyed by wind turbine noise than if they lived at greater distances or experienced lower estimated SPLs. Three of the studies attempted to reduce recall bias by masking the studies' intent and asking about multiple sources of annoyance. Adjustment for confounding did not completely explain the effect.

### *Other possible determinants of annoyance from wind turbines*

#### *Economic benefit*

Only one study (NL-07; reported in van den Berg et al. 2008 and Pedersen et al. 2009) assessed economic benefit as a possible determinant of reported noise annoyance from wind turbines. Respondents who received an economic benefit from the wind turbines were much less likely to report annoyance than those who did not receive an economic benefit. The OR for annoyance in those who received economic benefit relative to those who did not was 0.06 (95% CI 0.02, 0.23) after taking account of possible confounding by estimated SPL, visibility of wind turbines and area type (Pedersen et al. 2009, see Table 28). Thus, receiving an economic benefit from wind turbines *reduced* the odds of being annoyed by wind turbine noise.

Those living in a built-up area were less likely to benefit economically from wind turbines (2%) than those in rural areas (19%) (Pedersen et al. 2009).

Neither Pedersen et al. (2009) nor van den Berg et al. (2008), reporting on study NL-07, specified whether those who received economic benefits from wind turbines had a part in the decision regarding location of the wind turbines. Although it is possible that receiving an economic benefit reduced the likelihood of being annoyed, it is also possible that respondents who were favourable towards wind turbines prior to their construction (and less likely to be annoyed) were more likely to agree to have one placed close to their place of residence in exchange for an economic benefit. Given the cross-sectional design of study NL-07, the direction of the association cannot be determined.

Table 22 Association between estimated A-weighted sound pressure levels and annoyance (further details)

| Study | Self-reported outcome | Results |
|---|---|---|
| SWE-00<br>Pedersen and Persson Waye (2004)<br>Sweden<br>N[a]=319–333 | Annoyance (location not specified) | β=0.63, p<0.001, Exp(b) (OR) 1.9 (95%CI 1.5, 2.4) for increase in annoyance when moving from one sound category to the next[b]<br>Pseudo-$R^2$=0.13 |
| SWE-05<br>Pedersen and Persson Waye (2007)<br>Sweden<br>N=720–744 | Annoyance (location not specified) | <37.5 dB(A): 3–4%<br>37.5–40 dB(A): 6%<br>>40 dB(A): 15% |
| NL-07<br>Bakker et al. (2012)<br>The Netherlands<br><br>N=639–678 | Annoyance (outdoors) | <30 dB(A): 4/178 (2%)<br>30–35 dB(A): 16/213 (8%)<br>35–40 dB(A): 28/159 (18%)<br>40–45 dB(A): 17/93 (18%)<br>>45 dB(A): 8/65 (12%)<br>Total: 73/708 (10%) |
| | Annoyance outdoors (no economic benefit) | <30 dB(A): 4/166 (2%)<br>30–35 dB(A): 16/199 (8%)<br>35–40 dB(A): 28/140 (20%)<br>40–45 dB(A): 15/60 (25%)<br>>45 dB(A): 6/28 (21.4%)<br>Total: 69/586 (12%) |
| | Annoyance indoors (no economic benefit) | <30 dB(A): 2/167 (1.2%)<br>30–35 dB(A): 8/191 (4.2%)<br>35–40 dB(A): 12/140 (8.6)<br>40–45 dB(A): 15/60 (25%)<br>>45 dB(A): 4/21 (19.0%)<br>Total: 41/579 (7%) |

**Bolded values indicate statistically significant differences.**

Abbreviations: OR = odds ratio; CI = confidence interval

[a] Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases; that is, the respondents not answering single questions in the questionnaire.

[b] Upon being contacted, Professor Persson Waye clarified that this related to moving from any sound category to the next sound category, not just with respect to the reference category of <30 dB.

Table 23 Association between distance from nearest wind turbine and annoyance or disturbance

| Study | Outcome measure | Proportion affected by distance (km) from nearest industrial wind turbine | | OR (95%CI) |
|---|---|---|---|---|
| Morris (2012) Australia | | **0–5** **n=41** | **5–10** **n=52** | |
| | Disturbed by noise during day | 23/41 (56.1%) | 13/52 (25%) | **3.83 (1.59, 9.24)** |
| | Disturbed by noise during night | 22/41 (53.7%) | 15/52 (28.8%) | **2.86 (1.21, 6.74)** |

**Bolded values indicate statistically significant differences.**
Abbreviations: OR = odds ratio; CI = confidence interval

*Terrain, urbanisation and visibility*

Two studies looked at whether the type of terrain or urbanisation where the wind turbines and residences were located was associated with levels of annoyance (SWE-05 and NL-07). The results were slightly contradictory (Table 24). The Swedish study (SWE-05) reported that, even when estimated turbine noise exposure was controlled, respondents were more likely to be annoyed by 'wind turbine noise' if they lived in rural areas (compared with suburban), if they subjectively assessed the level of background noise as quiet or if they could see the wind turbine (Pedersen & Persson Waye 2007). The Dutch study (NL-07) found that there was a very slight association between annoyance and estimated SPLs when area type, visibility and economic benefit were controlled. However, consistent with SWE-00, living in a rural area near a main road was associated with reduced odds of being annoyed by wind turbine noise (living in a built-up area was the reference) when adjusted for estimated turbine SPLs, age, gender and economic benefit (van den Berg et al. 2008). This supports the concept of noise habituation; that is, people living in noisy areas are more habituated to noise than people living in quiet areas.

Both the Swedish (SWE-05) and Dutch studies (NL-07) reported that visibility of wind turbines increased the odds of noise annoyance to a large degree (although the actual magnitude of the effect was uncertain, as shown by the wide confidence intervals) (Table 24).

Table 24 Associations of terrain, urbanisation and visual factors with annoyance from wind turbine noise in multiple logistic regression models

| Study | Variables included in multiple logistic regression models | ORs for annoyance from wind turbine noise (95% CI)[a] |
|---|---|---|
| SWE-05 Pedersen and Persson Waye (2007) N=720–744 Sweden | Sound pressure level (dB(A)) | 1.1 (1.0, 1.3) |
| | Terrain (complex; flat) | 0.8 ( 0.4, 1.8) |
| | Sound pressure level (dB(A)) | 1.1 (1.0, 1.2) |
| | Suburban; rural | **3.8 (1.8, 7.8)** |
| | Sound pressure level (dB(A)) | 1.1 (1.0, 1.2) |
| | Suburban and flat (n=222) Reference category | 1.0 |
| | Suburban and complex (n=347) | 2.1 (0.6, 7.3) |
| | Rural and flat (n=157) | **5.2 (1.6, 16.7)** |
| | Rural and complex ground (n=28) | **10.1 (2.5, 41.6)** |
| | Sound pressure level (dB(A)) | 1.1 (0.9, 1.2) |
| | Subjective background noise (not quiet; quiet) | **3.6 (1.2, 10.7)** |
| | Sound pressure level (dB(A)) | 1.1 (0.9, 1.2) |
| | Vertical visual angle (degrees; +1 degree) | 1.2 (1.0, 1.4) |
| | Sound pressure level (dB(A)) | 1.1 (1.0, 1.2) |
| | Visibility (no; yes) | **10.9 (1.5, 81.9)** |
| NL-07 Pedersen et al. (2009) The Netherlands | Sound pressure level (dB(A)) | **1.1 (1.07, 1.21)** |
| | Economic benefit (no; yes) | **0.1 (0.02, 0.23)** |
| | Visibility (no; yes) | **13.7 (3.16, 57.4)** |
| | Area type (reference: rural) | |
| | Rural with main road | **0.3 (0.17, 0.71)** |
| | Built-up | **1.9 (1.02, 3.59)** |
| NL-07 Van den Berg et al. (2008) The Netherlands | Urbanisation[b] | |
| | Built-up area | 1.0 |
| | Rural area with a main road | **0.20 (0.08, 0.45)** |
| | Rural area without a main road | 0.55 (0.28, 1.08) |

**Bolded values indicate statistically significant differences.**
Abbreviations: OR = odds ratio; CI = confidence interval
[a] Odds ratios and 95% CIs have been calculated from published beta coefficients and standard errors.
[b] Adjusted for estimated turbine sound levels, age, gender and economic benefits.

*Attitudes towards wind turbines*

In all three European studies (SWE-00, SWE-05 and NL-07) data on attitudes towards wind turbines in general, attitudes towards the visual impact of wind turbines and subjective classifications of noise sensitivity of respondents were collected to ascertain how these factors are associated with reported annoyance from wind turbine sound (Table 25).

Pedersen and Persson Waye (2004) reported that, in the SWE-00 study, estimated SPL alone explained only 13% of the variance predicted by their model on wind turbine noise annoyance. When self-classified noise sensitivity was added to the logistic regression analysis, 18% of the variance was explained. However, when the attitude of the respondent towards the visual impact of wind turbines was added to estimated SPL in the model, 46% of the variance in noise annoyance was explained (Table 25)—suggesting that visual attitude is a strong predictor. These results are similar to the later Swedish study (SWE-05), which reported that a negative visual attitude increased the odds of being annoyed by the sound by over 14 times (Pedersen & Persson Waye 2007). Using data from the Dutch study (NL-07), Pedersen et al. (2009) undertook a multiple logistic regression analysis of the relationship between annoyance and estimated SPL (continuous scale), noise sensitivity, general attitude to wind turbines and visual attitude to wind turbines. The factor that had the greatest impact on annoyance was visual attitude, which had an OR of 2.8 per point increase on a 5-point scale. When visual attitude was assessed (with estimated SPL, age, sex and economic benefits controlled for, but not noise sensitivity or general attitude towards wind turbines), a negative attitude of the respondent towards the visual impact of wind turbines increased the odds of noise annoyance by over 4 times (OR=4.10, 95%CI 2.84, 5.91). It is unknown to what extent the general attitudes or visual attitudes towards wind farms precede the development of noise annoyance, or whether these attitudes changed in response to noise annoyance.

Table 25 Associations of noise sensitivity and attitudes to wind turbines with wind turbine noise annoyance

| Study | Variables included in univariate or multiple logistic regression models | ORs for annoyance from wind turbines (95% CI)[a] |
|---|---|---|
| SWE-00<br>Pedersen and Persson Waye (2004)<br>Sweden | Sound pressure level (dB(A)) | **1.8 (95%CI 1.5, 2.4)**<br>Pseudo-$R^2$=0.13 |
| | Sound pressure level (dB(A))<br>Noise sensitivity | **1.9 (95%CI 1.5, 2.4)**<br>**1.9 (95%CI 1.5, 2.4)**<br>Pseudo-$R^2$=0.18 |
| | Sound pressure level (dB(A))<br>General attitude (not negative; negative) | **1.9 (95%CI 1.5, 2.4)**<br>**1.7 (95%CI 1.3, 2.3)**<br>Pseudo-$R^2$=0.20 |
| | Sound pressure level (dB(A))<br>General attitude (not negative; negative)<br>Noise sensitivity | **1.9 (95%CI 1.5, 2.5)**<br>**1.8 (95%CI 1.3, 24.1)**<br>**1.8 (95%CI 1.2, 2.7)**<br>Pseudo-$R^2$=0.24 |
| | Sound pressure level (dB(A))<br>Visual attitude (not negative; negative) | **1.7 (95%CI 1.3, 2.3)**<br>**1.7 (95%CI 1.3, 2.3)**<br>Pseudo-$R^2$=0.46 |
| | Sound pressure level (dB(A))<br>Visual attitude (not negative; negative)<br>Noise sensitivity | **1.8 (95%CI 1.3, 2.4)**<br>**4.9 (95%CI 3.1, 7.7)**<br>1.25 (95%CI 0.8, 2.0)<br>Pseudo-$R^2$=0.47 |
| | Sound pressure level (dB(A))<br>Visual attitude (not negative; negative)<br>General attitude (not negative; negative)<br>Noise sensitivity | **1.8 (95%CI 1.3, 2.4)**<br>**5.1 (95%CI 3.1, 8.4)**<br>0.9 (95%CI 0.6, 1.3)<br>1.2 (95%CI 0.8, 1.9)<br>Pseudo-$R^2$=0.47 |
| SWE-05<br>Pedersen and Persson Waye (2007)<br>Sweden | Sound pressure level (dB(A)) | **1.1 (1.02, 1.26)** |
| | Noise sensitivity (not sensitive; sensitive) | **2.5 (1.14, 2.53)** |
| | Sound pressure level (dB(A))<br>General attitude (not negative; negative) | 1.1 (1.00, 1.25)<br>**13.4 (6.03, 29.59)** |
| | Sound pressure level (dB(A))<br>Visual attitude (not negative; negative) | **1.1 (1.01, 1.25)**<br>**14.4 (6.37, 32.44)** |
| NL-07 | Noise sensitivity (4-point scale) | **1.94 (1.51, 2.49)** |

| Study | Variables included in univariate or multiple logistic regression models | ORs for annoyance from wind turbines (95% CI)[a] |
|---|---|---|
| Van den Berg et al. (2008) The Netherlands | General attitude (5-point scale) | **3.18 (2.37, 4.26)** |
| | Visual attitude (5-point scale) | **4.10 (2.84, 5.91)** |
| | Visual judgement (scale) | **2.55 (1.74, 3.73)** |
| | Utility judgement (scale) | **1.68 (1.43, 2.47)** |
| NL-07 Pedersen et al. (2009) The Netherlands | Sound pressure level (dB(A)) | **1.1 (1.04, 1.17)** |
| | Noise sensitivity (5-point scale) | **1.4 (1.08, 1.87)** |
| | General attitude (5-point scale) | **1.7 (1.23, 2.39)** |
| | Visual attitude (5-point scale) | **2.8 (1.84, 4.35)** |

**Bolded values indicate statistically significant differences.**
Abbreviations: OR = odds ratio; CI = confidence interval
[a] Odds ratios and 95% CIs have been calculated from published beta coefficients and standard errors.
NB: where factors are grouped, they have been entered into a multiple logistic regression analysis together.

### *Association between annoyance and sleep and health outcomes*

Four studies reported on associations between annoyance due to wind turbine noise, sleep quality and health outcomes. Shepherd et al. (2011) reported that noise annoyance (from traffic, neighbours or other sources, including wind turbines) was negatively correlated with health to a similar degree in those living within 2 km of wind turbines ($r$=-0.31, p>0.05) and those living 8 km or more from turbines ($r$=-0.26, p<0.001). There were poor response rates in both the turbine and comparison groups (34% and 32% respectively), although this should not greatly affect measures of association within each group.

Pedersen (2011) assessed the relationship between annoyance with wind turbine noise (outdoors and indoors) and health outcomes in the two Scandinavian studies (SWE-00, SWE-05) and one Dutch study (NL-07). Annoyance outdoors was consistently associated with sleep interruption (Table 26), while two out of the three studies also showed a relationship between annoyance and headaches or irritability. One study demonstrated a paradoxical relationship between outdoor annoyance and reduced odds of self-reported tinnitus, but increased odds of self-reported diabetes or being tense and stressed (Table 26). This, and the lack of effect in the other studies, suggests that the results have been affected by confounding or chance. Annoyance indoors was consistently associated with sleep interruption, but other outcomes such as self-reported diabetes, headache, undue tiredness, being tense and stressed, and irritability were all associated with annoyance indoors in only one out of three studies (

Table 27). The cross-sectional design is ambiguous with respect to the direction of any of these associations; for example, it cannot distinguish between sleep interruption consequent on annoyance or annoyance consequent on sleep interruption. Similarly, the analyses that were undertaken in these studies do not account for all plausible confounders so it is unclear whether factors other than annoyance with wind turbine noise were responsible for the apparent association with sleep interruption.

Table 26 Association between annoyance outdoors due to wind turbine noise and health outcomes

| Study | Self-reported health outcomes | SWE-00[a] OR (95%CI) N[c]=319–333 | SWE-05[a] OR (95%CI) N[c]=720–744 | NL-07[b] OR (95%CI) N[c]=639–678 |
|---|---|---|---|---|
| Comparison of studies NL-07, SWE-00 and SWE-05 Pedersen (2011) The Netherlands and Sweden | Sleep interruption | **2.26 (1.76, 2.90)** | **1.71 (1.35, 2.17)** | **1.78 (1.49, 2.14)** |
| | Chronic disease | 0.90 (0.71, 1.08) | 0.90 (0.74, 1.26) | 0.98 (0.81, 1.19) |
| | Diabetes | 0.69 (0.55, 1.22) | 0.71 (0.40, 1.28) | **1.70 (1.14, 2.56)** |
| | High blood pressure | 0.82 (0.55, 1.22) | 1.10 (0.84, 1.45) | 0.86 (0.64, 1.17) |
| | Cardiovascular disease | 1.07 (0.58, 1.98) | 1.00 (0.64, 1.55) | 0.95 (0.65, 1.38) |
| | Tinnitus | 1.55 (0.95, 2.53) | **0.88 (0.60, 0.98)** | 0.82 (0.45, 1.48) |
| | Impaired hearing | 1.03 (0.96, 1.19) | 0.78 (0.51, 1.21) | 1.13 (0.76, 1.67) |
| | Headache | **1.24 (1.01, 1.51)** | 1.04 (0.86, 1.26) | **1.25 (1.04, 1.50)** |
| | Undue tiredness | 1.22 (1.00, 1.49) | 1.12 (0.93, 1.35) | 1.10 (0.93, 1.31) |
| | Tense and stressed | 1.25 (1.00, 1.56) | 1.22 (1.00, 1.50) | **1.27 (1.07, 1.50)** |
| | Irritable | **1.36 (1.10, 1.69)** | 1.22 (1.00, 1.49) | **1.27 (1.07, 1.50)** |

**Bolded values indicate statistically significant differences.**
Abbreviations: OR = odds ratio; CI = confidence interval
[a] Adjusted for age, gender, and estimated A-weighted sound pressure levels.
[b] Adjusted for age, gender, economic benefits, and estimated A-weighted sound pressure levels.
[c] Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases, that is, the respondents not answering single questions in the questionnaire.

Table 27 Association between annoyance indoors due to wind turbine noise and health outcomes

| Study | Self-reported health outcomes | SWE-00[a] OR (95%CI) N[c]=319–333 | SWE-05[a] OR (95%CI) N[c]=720–744 | NL-07[b] OR (95%CI) N[c]=639–678 |
|---|---|---|---|---|
| Comparison of studies NL-07, SWE-00 and SWE-05 Pedersen (2011) The Netherlands and Sweden | Sleep interruption | **2.62 (1.90, 3.61)** | **2.58 (1.79, 3.71)** | **2.03 (1.66, 2.47)** |
| | Chronic disease | 0.93 (0.69, 1.25) | 0.94 (0.68, 1.31) | 1.05 (0.09,1.28) |
| | Diabetes | 0.73 (0.30, 1.75) | 0.59 (0.22, 1.59) | **1.62 (1.10, 2.40)** |
| | High blood pressure | 0.07 (0.36, 1.19)[d] | 0.85 (0.52, 1.38) | 0.83 (0.59, 1.16) |
| | Cardiovascular disease | 0.99 (0.46, 2.17) | 0.97 (0.49, 1.94) | 0.76 (0.47, 1.22) |
| | Tinnitus | 1.25 (0.77, 2.05) | 0.57 (0.24, 1.33) | 0.67 (0.28, 1.57) |
| | Impaired hearing | 1.14 (0.72, 1.79) | 0.56 (0.24, 1.32) | 1.20 (0.80, 1.80) |
| | Headache | 1.07 (0.83, 1.37) | 1.11 (0.81, 1.52) | **1.28 (1.06, 1.54)** |
| | Undue tiredness | **1.36 (1.05, 1.77)** | 1.00 (0.95, 1.80) | 1.15 (0.96, 1.37) |
| | Tense and stressed | 1.03 (0.79, 1.35) | 1.07 (0.77, 1.48) | **1.24 (1.04, 1.48)** |
| | Irritable | 1.22 (0.93, 1.61) | 1.23 (0.80, 1.72) | **1.26 (1.06, 1.50)** |

**Bolded values indicate statistically significant differences.**
Abbreviations: OR = odds ratio; CI = confidence interval
[a] Adjusted for age and gender.
[b] Adjusted for age, gender, and economic benefits.
[c] Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases, that is, the respondents not answering single questions in the questionnaire.
[d] OR and 95% CI as printed in Pedersen 2011.

*Multivariate analysis*

Pedersen et al. (2009) used a multiple logistic regression model to simultaneously examine associations between estimated A-weighted SPL, economic benefit, visibility of wind turbines and area type with annoyance, using the response variable 'not annoyed / annoyed by the wind turbine sound' (Table 28).

Visibility of wind turbines, economic benefit from wind turbines and type of area of residence were strongly associated with reported annoyance from wind turbine noise. These associations were of greater magnitude than the association between estimated SPL and annoyance, meaning that these other factors had more impact on reported noise annoyance than the actual noise level. However, the weak association between estimated SPL and noise annoyance remained even after controlling for economic benefit, turbine visibility and area type (Table 28; Pedersen et al. 2009).

Receiving an economic benefit from wind turbines *reduced* the odds of being annoyed by wind turbine noise by more than 10 times, and living in a rural area near a main road reduced the odds by two-thirds, compared with living in a rural area without a main road. It should be noted that benefiting economically did not influence the *perception* of the sound, whereas estimated SPL, wind turbine visibility and living near a main road did influence perception (Pedersen et al. 2009).

Table 28 Independent predictors of annoyance from wind farms in the Dutch study (NL-07)

| Study | Independent predictors | Odds ratios for annoyance from wind turbines[a] |
|---|---|---|
| NL-07<br>Van den Berg et al. (2008)<br>The Netherlands | Age (OR per year)[b]<br>Gender (male; female)[b]<br>Economic benefits (no; yes)[b] | **OR=1.03 (95%CI 1.01, 1.05)**<br>OR=0.93 (95%CI 0.56, 1.53)<br>**OR=0.05 (95%CI 0.01, 0.19)** |
| NL-07[c]<br>Pedersen et al. (2009)<br>The Netherlands<br>n=639–678 | Sound pressure level (dB(A))<br>Economic benefit (no; yes)<br>Visibility (no; yes)<br>Area type (reference: rural)<br>Rural<br>Rural with main road<br>Built-up | **OR 1.14 (95%CI 1.08, 1.20)**<br>**OR 0.06 (95%CI 0.02, 0.23)**<br>**OR 13.7 (95%CI 3.2, 59.0)**<br><br>OR 1.00<br>**OR 0.34 (95%CI 0.17, 0.71)**<br>**OR 1.92 (95%CI 1.02, 3.59)** |

**Bolded values indicate statistically significant differences.**
Abbreviations: OR = odds ratio; CI = confidence interval
[a] Beta coefficients and standard errors have been used to transform to odds ratios and 95% CIs.
[b] Adjusted for estimated sound pressure levels.
[c] All listed determinants were included as independent predictors in a multivariate logistic regression and thus the reported odds ratios control for the effects of the other predictors in the model.

## *SQ3. IS THERE ANY RELIABLE EVIDENCE OF AN ASSOCIATION BETWEEN INFRASOUND AND LOW-FREQUENCY NOISE FROM WIND TURBINES AND ADVERSE HEALTH EFFECTS?*

There were no studies obtained in the systematic review searches that reported specifically on infrasound and low-frequency noise exposures from wind turbines.

## SUMMARY: DIRECT EVIDENCE ON NOISE

*SQ1. Is there any reliable evidence of an association between distance from wind turbines and adverse health effects?*

*SQ2. Is there any reliable evidence of an association between audible noise (greater than 20 Hz) from wind turbines and adverse health effects?*

*SQ3. Is there any reliable evidence of an association between infrasound and low-frequency noise from wind turbines and adverse health effects?*

Seven cross-sectional studies reported on the association between estimated noise levels or distance from wind turbines and self-reported adverse health effects. Their cross-sectional design means that it is not certain, or not known, whether onset of any possible adverse health effect preceded or followed the beginning of a participant's exposure to wind turbines. Four of the seven studies sought to mask participants to the intent of the research (i.e. investigating the effects of wind farms on humans) but it is not known whether this was effective. Response rates varied from 32% to 68% of potential participants contacted. Low response rates could have biased survey results (selection bias); for example, those near wind turbines and suffering from a health problem might have been more likely to respond, particularly if the intent of the study was evident. One study (Krogh et al. 2011), which lacked a systematic recruitment method and encouraged people with health problems to participate, would have been particularly prone to bias. Three studies used validated questionnaires in common use but supplemented them with author-developed items (NL-07; Nissenbaum, Aramini & Hanning 2012; Shepherd et al. 2011), while the other studies used questionnaires that were either author-developed or of uncertain origin. The validity of these other questionnaires is not known. Given these limitations, the findings of these studies should be interpreted cautiously.

Six studies reported on self-assessments of physical health problems (i.e. general health, any chronic disease, diabetes, high blood pressure, cardiovascular disease, tinnitus, hearing impairment, migraine and headache) and whether respondents had approached a doctor. Single studies showed associations between estimated A-weighted sound pressure levels and self-reported tinnitus or diabetes, but these findings were not replicated in other studies. Findings were not adjusted for all possible confounders and could also have been due to chance effects (as a consequence of conducting multiple statistical tests). None of the other physical health conditions were significantly associated with wind turbine exposure, whether assessed by proximity of a residence to a wind turbine or by estimated wind turbine sound pressure level at a residence.

## SUMMARY (CONT.)

Five studies assessed the relationship between estimated wind turbine noise exposure and indicators of mental health. In only one of the five studies (Nissenbaum, Aramini & Hanning 2012) was greater proximity to wind turbines associated with poorer self-reported mental health. Respondents in this study were not masked to the intent of the study (at risk of recall bias).

Chance, bias and confounding are possible explanations for the few observed positive associations between physical and mental health and exposure to wind turbines.

The relationship between distance from wind turbines and quality of life was assessed by three studies. One study (Shepherd et al. 2011) that attempted to mask participants to study intent and used a validated questionnaire reported a positive association between distance from wind turbines and overall quality of life. The other two studies used author-formulated questions and did not mask the intent of the study and found similar results. One study found that the majority of people reported that their quality of life had altered since living within 2400 metres of a wind turbine (Krogh et al. 2011), while the remaining study reported a 74% difference in those wishing to move from the vicinity of a turbine (less than 1.4 km) when compared with residents living further away (over 3 km) (Nissenbaum, Aramini & Hanning 2012). Bias and confounding are possible explanations for the observed associations.

Aspects of self-reported sleep were recorded in all seven studies. Most of the studies were consistent in reporting poorer sleep (predominantly sleep interruption and poorer sleep quality) with greater estimated exposure to audible noise or shorter residential distance from wind turbines. No objective measures of sleep quality were used and possible confounding was not consistently controlled. In the SWE-00, SWE-05 and NL-07 studies the association of objective estimates of *sound pressure* level with sleep interruption was not as strong as the associations of subjective *annoyance with wind turbine noise* and sleep interruption.

Annoyance is not a health outcome but was considered relevant to this review due to its association with stress, which is a possible mediator or moderator of health outcomes. Four studies examined the association between annoyance and wind turbine noise. Noise was measured as estimated sound pressure level or distance from wind turbines. The studies were consistent in observing that annoyance was greater when noise level was greater or distance to a wind turbine was less. This association persisted, although it was weaker, after taking account of possible confounding between exposure to wind turbines and age, gender, economic benefit from wind turbines, visibility of wind turbines and type of area of residence.

## SUMMARY (CONT.)

The association between estimated noise level and annoyance was significantly affected by the individuals' visual attitude to wind turbines (i.e. whether they found them beautiful, or ugly and unnatural) in the three studies that assessed this as a potential confounding or modifying factor.

Visual attitude to wind turbines was a much stronger predictor of annoyance than estimated sound pressure level. Bias and confounding are possible explanations for the associations observed between exposure to wind turbines and annoyance.

*Is there any reliable evidence of an association between annoyance from wind turbines and adverse health effects?*

Three cross-sectional studies that attempted to mask participants to study intent provided evidence on the association between annoyance from wind turbines and self-reported health, adjusting for estimated audible noise exposure (and age, gender and economic benefit from wind turbines in one study). Annoyance indoors and outdoors was consistently positively associated with sleep interruption but bias and confounding are possible explanations for this association. Less consistent effects were shown for the association between outdoor annoyance and headaches or irritability (two studies), or self-reported diabetes, being tense and stressed, or reduced odds of self-reported tinnitus (one study apiece). This lack of consistency was also shown for the association between indoor annoyance and self-reported diabetes, headaches, undue tiredness, being tense and stressed, and irritability (one study apiece).

There were no studies available that specifically reported on the association between adverse health effects and infrasound and low-frequency noise measured near wind turbines.

A summary of the evidence-base informing the association between estimated noise exposure from wind farms and health outcomes is given in Box 3.

## Box 3 Evidence statement matrix for noise

<table>
<tr><td colspan="3">Key question:<br>Is there any reliable evidence of an association between audible noise (greater than 20 Hz) from wind turbines and adverse health effects? If so:<br>A. How strong is this association?<br>B. How does the strength of this association relate to <u>distance</u> from wind turbines? [Systematic Review question on distance has been merged here]<br>C. Might this association be explained by:<br>i. chance?<br>ii. bias? or<br>iii. confounding?</td><td>Bakker et al. (2012); Nissenbaum, Aramini and Hanning (2012); Pedersen and Persson Waye (2004), (2007); Krogh et al (2011); Morris (2012); Shepherd et al. (2011)</td></tr>
<tr><td colspan="4">1. Evidence-base (Number of studies, level of evidence and risk of bias and confounding in the included studies)</td></tr>
<tr><td rowspan="4">7 level IV aetiology studies (cross-sectional studies)</td><td>A</td><td colspan="2">One or more level I studies with a low risk of bias or several level II studies with a low risk of bias and confounding</td></tr>
<tr><td>B</td><td colspan="2">One or two level II studies with a low risk of bias or SR/several level III studies with a low risk of bias and confounding</td></tr>
<tr><td>C</td><td colspan="2">One or two level III studies with a low risk of bias or level I or II studies with a moderate risk of bias and confounding</td></tr>
<tr><td>D</td><td colspan="2">Level IV studies or level I to III studies/SRs with a high risk of bias and confounding</td></tr>
<tr><td colspan="4">2. Consistency (If only one study was available, rank this component as ‘not applicable’)</td></tr>
<tr><td rowspan="5">No associations between wind turbine exposure and physical or mental health effects were consistently reported in multiple studies.<br>All three studies that reported on it found an association of wind turbine exposure with poorer quality of life, but only one study used a validated questionnaire and masked the intent of the study from participants. All four studies that examined it reported that wind turbine exposure was associated with interrupted or poorer sleep. All four studies that examined it, reported an association of wind turbine exposure with annoyance—the intent of three of these studies was masked from participants. Selection bias and confounding are possible explanations for these associations.</td><td>A</td><td colspan="2">All studies consistent—for one relevant non-health effect (annoyance) and one health related effect (sleep disturbance/sleep quality)</td></tr>
<tr><td>B</td><td colspan="2">Most studies consistent and inconsistency can be explained</td></tr>
<tr><td>C</td><td colspan="2">Some inconsistency, reflecting genuine uncertainty around question—for one health related effect (quality of life)</td></tr>
<tr><td>D</td><td colspan="2">Evidence is inconsistent—for all reported health effects</td></tr>
<tr><td>NA</td><td colspan="2">Not applicable (one study only)</td></tr>
</table>

<table>
<tr><td colspan="3">3. Population health impact (Indicate in the blank space below if the study results varied according to some unknown factor (not simply study quality or sample size) and thus the population health impact of the exposure could not be determined; or whether the impact could not be determined because the studies were underpowered and could not be meta-analysed. Otherwise, provide justification for your selection of the A–D rating, i.e. the size of the effect and precision of the estimate of adverse health effects)</td></tr>
<tr><td rowspan="4">The very limited evidence of any impact of wind turbine exposure on self-reported physical and mental health effects could be explained by chance, bias or confounding.<br><br>While the evidence for effects of wind turbine exposure on sleep and quality of life was inconsistent and possibly explained by bias or confounding, the associations observed suggest the possibility of a moderate impact on exposed people. While there was consistent evidence of an association between wind turbine exposure and annoyance, the association was weak when adjusted for plausibly confounding variables. Thus any health-related impact of annoyance, if there is one, would probably be small.</td><td>A</td><td>Very large</td></tr>
<tr><td>B</td><td>Substantial</td></tr>
<tr><td>C</td><td>Moderate—for health-related effects (sleep disturbance/sleep quality and quality of life)</td></tr>
<tr><td>D</td><td>Slight/restricted—for health effects and a relevant non-health effect (annoyance)</td></tr>
<tr><td colspan="3">4. Generalisability (How well does the body of evidence match the population being targeted by the NHMRC advice?)</td></tr>
<tr><td rowspan="4">Poor response rates. Unknown whether responders are similar to non-responders and thus representative of all residents near wind farms.</td><td>A</td><td>Evidence directly generalisable to target population</td></tr>
<tr><td>B</td><td>Evidence directly generalisable to target population with some caveats</td></tr>
<tr><td>C</td><td>Evidence not directly generalisable to the target population but could be sensibly applied</td></tr>
<tr><td>D</td><td>Evidence not directly generalisable to target population and hard to judge whether it is sensible to apply</td></tr>
<tr><td colspan="3">5. Applicability (Is the body of evidence relevant to the Australian setting for the exposure?)</td></tr>
<tr><td rowspan="4">One study was done in Australia. Remaining studies were done in New Zealand, Canada, USA, The Netherlands, and Sweden (two studies). Since European and North American countries have a longer history of, and more extensive, wind turbine development and a greater population density than Australia, it is possible that wind turbine exposure in Australia is qualitatively and quantitatively different from the exposures contributing most evidence.</td><td>A</td><td>Evidence directly applicable to Australian exposure setting</td></tr>
<tr><td>B</td><td>Evidence applicable to Australian healthcare exposure setting with few caveats</td></tr>
<tr><td>C</td><td>Evidence probably applicable to Australian exposure setting with some caveats</td></tr>
<tr><td>D</td><td>Evidence not applicable to Australian exposure setting</td></tr>
<tr><td colspan="3">Other factors (Indicate here any other factors that you took into account when assessing the evidence-base (e.g. issues that might cause the group to downgrade or upgrade the recommendation, such as the biological plausibility evidence presented in Background Question 4)</td></tr>
</table>

No studies in the systematic review specifically reported on the health impact of infrasound and low frequency noise (ILFN). Estimates of A-weighted audible wind turbine sound at subjects' residences and distance of residences from wind turbines probably misclassify exposure to infrasound from wind turbines and studies based on them might, therefore, under-estimate the strength of any associations of wind turbine infrasound with health effects that might be present.

The information addressing Background Questions 3 and 4 (see relevant sections in the report) was not sufficiently persuasive to result in an upgrade of the evidence rating obtained from the direct evidence. A mechanism of action for ILFN to cause adverse health effects could not be identified. The effect of infrasound in laboratory circumstances was based on the measurement of intermediate physiological outcomes and produced inconsistent findings of uncertain applicability to the wind turbine setting.

The quality of the evidence-base and the evidence for direct health effects were given greatest weight when formulating the overall rating.

**EVIDENCE STATEMENT MATRIX**

*Please summarise the synthesis of the evidence relating to the key question, taking all the above factors into account.*

| Component | Rating | Description |
|---|---|---|
| **1. Evidence-base** | D | 7 level IV studies with a high risk of bias and confounding |
| **2. Consistency** | D<br>A<br>C | Evidence is inconsistent—for health effects<br>All studies consistent—for one relevant non-health effect (annoyance) and one health related effect (sleep disturbance/sleep quality)<br>Some inconsistency, reflecting genuine uncertainty around question—for one health related effect (quality of life) |
| **3. Population health impact** | D<br>C | Very limited evidence for any health effects and an apparently very weak effect of annoyance, after adjustment for plausible confounding, are consistent with slight population health impact<br>While associations of wind turbines with poorer sleep and quality of life are uncertain, if real, their impacts on the exposed population would probably be moderate |
| **4. Generalisability** | D | Evidence not directly generalisable to target population and hard to judge whether it is sensible to apply |
| **5. Applicability** | C | Evidence probably applicable to Australian exposure setting with some caveats |

| *Evidence statement* | *Evidence rating* |
|---|---|
| There is no consistent evidence that noise from wind turbines—whether estimated in models or using distance as a proxy—is associated with self-reported human health effects. Isolated associations may be due to confounding, bias or chance.<br>There is consistent evidence that noise from wind turbines—whether estimated in models or using distance as a proxy—is associated with annoyance, and reasonable consistency that it is associated with sleep disturbance and poorer sleep quality and quality of life. However, it is unclear whether the observed associations are due to wind turbine noise or plausible confounders. | D |

## Parallel evidence

*BQ4. IS THERE BASIC BIOLOGICAL EVIDENCE, OR EVIDENCE FROM RESEARCH INTO OTHER CIRCUMSTANCES OF HUMAN EXPOSURE TO NOISE EMISSIONS, THAT MAKE IT PLAUSIBLE THAT WIND TURBINES CAUSE ADVERSE HEALTH EFFECTS?*

Audible noise at high levels has been shown to disrupt sleep and cause hearing impairment and other health problems. Internationally, the environmental burden of disease due to environmental noise has been the focus of extensive study (WHO 2011). A common approach in this research has been through quantitative risk assessment[34]. The working group of the WHO European Centre for Environment and Health estimated the annual burden of disease in the European Union due to audible noise based on the following endpoints (WHO 2011):

- cardiovascular disease;
- cognitive impairment;
- sleep disturbance;
- tinnitus; and
- annoyance[35].

The working group noted for each of these endpoints that:

1. in recent years the evidence from epidemiological studies of association between exposure to noise from road traffic and aircraft and ischaemic heart disease and hypertension has increased. Road traffic noise has been shown to possibly increase the risk of both these diseases, albeit the confidence intervals of pooled effects from meta-analyses did not rule out chance effects. Very few studies on the cardiovascular effects of exposure to rail traffic noise are available;
2. the extent to which noise impairs cognition, particularly in children, has been the subject of experimental and epidemiological studies;
3. in epidemiological studies, self-reported sleep disturbance is the most commonly used and accessible outcome indicator because the alternative method—electrophysiological measurement—is costly, difficult to conduct for large samples, and may be a sleep-influencing factor (i.e. a source of bias);
4. the study of tinnitus[36] due to excessive noise has a long history, with 50–90% of patients exposed chronically to high noise levels reporting tinnitus. In some people, tinnitus can cause sleep disturbance, effects on cognition, communication problems, anxiety, depression, psychological distress, frustration, tension, irritability, inability to work, reduced efficiency and restricted participation in social activities; and

[34] Risk assessment refers to hazard identification, the assessment of population exposure and the determination of appropriate exposure–response relationships (WHO 2011).

[35] Annoyance was selected for burden of disease estimation in consideration of the WHO definition of health as ‘a state of complete physical, mental and social wellbeing and not merely the absence of disease’ (WHO 1948).

[36] Tinnitus is the conscious perception of sound in the absence of an external source (Elgoyhen & Langguth 2010).

5. high levels of annoyance due to environmental noise can be considered as an environmental health burden, which can be assessed using standardised questionnaires (WHO 2011).

The Regional Office for Europe of the WHO has also conducted extensive research into the effects of audible environmental noise during the night hours, with an emphasis on sleep and the downstream effects of sleep disturbance (WHO 2009). In order to inform guidelines on night noise in Europe, the WHO Environment and Health working group selected a number of health-related endpoints in order to categorise evidence of association between those endpoints and night noise as either 'sufficient' or 'limited'. Definitions for the terminology as applied by the working group are provided in Table 29.

The WHO working group concluded that there is sufficient evidence that night noise is related to self-reported sleep disturbance, use of pharmaceuticals, self-reported health problems and insomnia-like symptoms. These effects can lead to a considerable burden of disease in the population. For other effects including hypertension, myocardial infarction and depression, limited evidence was found. Although these studies were few or not conclusive, a biologically plausible pathway could be constructed from the evidence. The remaining key conclusions from the working group were that (WHO 2009):

- sleep is a biological necessity and disturbed sleep is associated with a variety of adverse health effects;
- there is *sufficient* evidence that night noise exposure causes self-reported sleep disturbance, increased medicine use, increased body movements and insomnia;
- while sleep disturbance due to noise is viewed as a health issue in itself (insomnia), it leads to downstream consequences for health and wellbeing;
- there is *limited* evidence that disturbed sleep from night noise causes fatigue, accidents and reduction in performance; and
- there is *limited* evidence that noise at night causes changes in hormonal levels and clinical conditions such as cardiovascular disease, depression and other mental illness (plausible biological model available with *sufficient* evidence for elements of the causal chain).

Table 29 Definitions of 'sufficient' and 'limited' evidence as per the WHO working group of the European Centre for Environment and Health

| 'Sufficient' evidence | 'Limited' evidence |
|---|---|
| A causal relationship has been established between exposure to noise and a health effect. In studies where coincidence, bias and distortion could reasonably be excluded, the relationship could be observed. The biological plausibility of the noise leading to the health effect is also well established. | A relationship between the noise and the health effect has not been observed directly, but there is available evidence of good quality supporting the causal association. Indirect evidence is often abundant, linking noise exposure to an intermediate effect of physiological changes which lead to the adverse health effects. |

Source: WHO (2009)

The health effects of noise within the audible range, especially from road traffic[37], have been extensively studied. However, extrapolation of these findings to the wind farm context is not simple. As distance is highly correlated with estimated SPL (van den Berg et al. 2008) it is not expected that substantial audible noise exposures (>45 dB(A)) would be associated with modern wind turbines at distances of more than about 280 m, although this might vary by terrain, type of wind turbine and wind conditions (Ellenbogen et al. 2012); see page 68 for further information. Sleep disturbance from noise exposure alone is not plausible at noise levels of 30 dB(A) and below, and has only modest effects at 30-40 db(A) (WHO 2011).

ILFN is made up of long waves, while moderate to high frequency noise consists of relatively short waves. Noise at high frequency (pitch) attenuates in intensity (loudness) over much shorter distances and does not pass easily through doors and windows, unlike ILFN which can more easily pass through these obstacles. Hearing becomes gradually less sensitive as frequency decreases, so for humans to perceive infrasound and low frequencies, the SPL needs to be high. Indoors, room resonances can *increase* SPLs and lead to variations of SPL inside a room for low frequency noise (Persson Waye 2004; Roberts & Roberts 2009).

ILFNs are, therefore, the exposures of most relevance at the range of distances typically observed between residential dwellings and commercial wind turbines (see 'Noise' section, page 59).

The parallel evidence identified for Background Question 4 concerning the effects of ILFN on human health is summarised in Table 30. This parallel evidence involved the experimental exposure of human subjects to ILFN produced in a laboratory setting. Systematic measurement of biological or psychological variables before, during or after the ILFN exposure was undertaken, and/or in relation to periods of non-exposure as well as periods of exposure. This evidence was used to address the biological plausibility that wind farms could cause adverse health effects. The specific limitations of each of the studies are also stated.

## Infrasound and low-frequency noise

In this section ILFN will be considered to be sound composed mainly or exclusively of frequencies below 250 Hz.

The ILFN exposure produced in the available laboratory studies was frequently greater than (usually A-weighted) 80 dB and ranged between 40 and 144 dB. The impact of ILFN on the measured outcomes was largely inconsistent and inconclusive (Table 30). Mainly intermediate outcomes, including physiological changes such as heart rate, cortisol level, respiratory rate and blood pressure, were considered in the available studies (Alford et al. 1966; Danielsson & Landstrome 2009; Fuchs, Verzini & Nitardi 1995; Mills et al. 1983; Takigawa, Sakamoto & Murata 1991; Verzini et al. 1999; Waye et al. 2002, 2003). Health outcomes were not considered. The data suggest that low-frequency noise at high SPLs may elicit a temporary threshold shift (TTS) in hearing (Alford et al. 1966; Mills et al. 1983) and lead to statistically significant, albeit small and

[37] The majority of environmental noise discussed previously in this section was from road traffic (WHO 2011).

inconsistent, changes in systolic and diastolic blood pressure, and pulse or heart rate, which are of uncertain significance to health. Other outcomes studied included subjectively measured endpoints such as anxiety, mood and sleep disturbance. Studies of exposure from non-wind-turbine sources investigating a plausible relationship between ILFN and health generally did not present sufficient data to assess similarities or differences between exposed and non-exposed groups of individuals. The studies were of small sample size, and so a reasonably even distribution of potential confounders could not be assured in parallel study designs or pre-test/post-test designs (4 of 8 studies). Neither of these was an issue for the other four studies because each subject in all exposures was their own control. There were not enough studies reporting on exactly the same intervention or outcomes to address the 'replicability' criterion for causation (modified Bradford Hill Guidelines, see Table 5). Finally, there was inconsistency across the studies with respect to the influence of infrasound on physiological measures, and so the available evidence did not meet the 'similarity' criterion.

Table 30 Parallel evidence examining the association between infrasound and low-frequency noise (ILFN) and adverse health effects

| Study | Design | Exposure | Outcome | Limitations |
|---|---|---|---|---|
| Fuchs, Verzini and Nitardi (1995) | Randomised controlled trial (RCT)<br>n=25 university students (aged 18–25 years) randomly assigned to 5 groups (four 'experimental' arms corresponding to different levels of ILFN and one 'control' group).<br>To simulate infrasonic noise environments, with high levels of infrasound, a pressure chamber was built by the investigators (optimal operation range: 10–80 Hz). | 30-minute exposure to ILFN conditions: 10 Hz/110 dB, 20 Hz/97 dB, 40 Hz/89 dB and 80 Hz/68 dB followed by 10 minutes without sound stimulus. Levels were fixed at approximately 25 dB over Vercammen's mean auditory thresholds. | Mean hearing thresholds, physiological parameters, corporal sensations, annoyance or degree of 'agreeability' measured. | Small sample size (particularly spread across 5 groups).<br>Longer time spent in exposure to ILFN (30 minutes) group compared with that in the no-exposure group (10 minutes). |

**Results**

*ANOVA for repeated measurements on heart rate (dependent variable) and experimental condition (independent variable)*

| *F*-statistic | p value |
|---|---|
| 4.96 | 0.038 |

Note: the *F*-statistic is for the difference between HR1 ('first difference of heart rate') and HR2 ('second difference of heart rate'); 'first' denotes the difference between heart rate registered before noise exposure and the last measurement registered during exposure, while 'second' denotes the difference between the last measurement registered during exposure and the last measurement registered after the 10-minute period without sound stimulus.

**Summary**

There were no statistically significant differences in physiological variables between the groups reported from this study. While heart rate HR1 was statistically

| Study | Design | Exposure | Outcome | Limitations |
|---|---|---|---|---|
| significantly higher than HR2, this difference relates to variation in heart rate over time in the experiment, rather than variation between groups. | | | | |
| Verzini et al. (1999) | RCT<br>n=22 students (aged 18–25 years) assessed for normal hearing, randomly allocated to 3 exposure phases (1-week interval between phases). | Phase 1: 15 minutes of quiet preceding 30-minute exposure to 10 Hz/110 dB tone, followed by 15 minutes of quiet.<br>Phase 2: 15 minutes of quiet preceding 30-minute exposure to a boiler noise (1/3 octave band centred on 10 Hz, level 105±2 dB followed by 15 minutes of quiet.<br>Phase 3: control phase—60 minutes without sound stimulus exposure. | Physiological endpoints: heart and respiratory rates, peripheral temperature and galvanic skin exposure.<br>Subjective assessment of responses (see 'Results' for further details). | Only significant results concerned the subjective mood-based measures, not the objective physiological endpoints.<br>Subjective outcomes are more prone to bias if an individual is not masked to study intent and has strong prior beliefs. |

| Study | Design | Exposure | Outcome | Limitations |
|---|---|---|---|---|

**Results**

No statistically significant differences in the physiological parameters were observed.

*ANOVA for subjective assessments with experimental condition as the grouping factor and subjective responses as dependent variables*

| Scales | *F*-statistic | p value |
|---|---|---|
| Agreeable/disagreeable | 25.45 | $p \leq 0.001$ |
| Beneficial/harmful | 41.02 | $p \leq 0.001$ |
| Pleasant/unpleasant | 8.56 | $p \leq 0.001$ |
| Acceptable/unacceptable | 6.02 | $p \leq 0.005$ |
| Strong/weak | 3.42 | $p \leq 0.043$ |
| Shrill/soft | 5.44 | $p \leq 0.008$ |
| Arousing/drowsy | 10.49 | $p \leq 0.001$ |
| Exciting/calm | 9.41 | $p \leq 0.001$ |
| Soothing/startling | 21.03 | $p \leq 0.001$ |
| Concentrating/distracting | 22.35 | $p \leq 0.001$ |
| Harmonious/non-harmonious | 20.87 | $p \leq 0.001$ |

**Summary**

There were no statistically significant differences among the exposure conditions for any of the physiological variables measured (means or other summary parameters were not reported for the physiological experiments). However, each exposure condition was statistically significantly associated with each subjective response; these subjective assessments were, in each case, more adverse under each noise exposure condition than under the control condition.

| Study | Design | Exposure | Outcome | Limitations |
|---|---|---|---|---|
| Takigawa, Sakamoto and Murata (1991) | Cross-over RCT to study impact of infrasound on: eye movement (n=25 healthy males, aged 22–24 years); body sway (n=34 healthy males, aged 21–24 years); pulse-wave (n=9 healthy males and females aged 25–55 years). | The subjects were exposed to two kinds of sound: wide octave band noise (frequency range: 100–10,000 Hz); narrow band infrasound (frequency range: 3–7 Hz).<br>Noise intensity was 95 dB(A) and 70 dB(A), while the SPL of the infrasound was 95 dB.<br>Order of exposure to the different kinds of sound was randomly assigned. | (1) Amplitude of involuntary eye movement (subject's eyes first open and then closed for 45 seconds).<br>(2) Body sway was measured as movement from the centre of gravity of a subject in a standing position by using the regular triangle platform method.<br>(3) Pulse-wave recording was made continuously under pre-exposure conditions for 1 minute, during exposure to either of the sounds for 3 minutes, and finally under post-exposure conditions for 1 minute. | The applicability of these findings, from an acute exposure setting to the chronic exposure setting, where acclimatisation might be expected (as in wind farm setting), is unknown. |

**Results**

With the exception of p values, all data were presented graphically and cannot be reproduced in this table. A narrative summary is provided below.

**Summary**

Eye movement: Eyes open—no significant differences in the amount of total amplitude observed between pre-exposure and the other exposure conditions. Eyes closed—the amount of total amplitude was higher in the infrasound exposure phase compared with the pre-exposure phase ($p<0.025$), and not significantly different between the noise exposure and the pre-exposure phase.

Body sway: No statistically significant differences between exposure and pre-exposure periods for wide octave band noise. Significant reduction in body sway

| Study | Design | Exposure | Outcome | Limitations |
|---|---|---|---|---|
| (less than 1% difference) in high frequency band of infrasound between pre-exposure and exposure conditions ($p<0.05$).<br>Pulse wave: Pulse wave height was statistically significantly reduced upon either exposure compared with pre-exposure ($p<0.01$).<br>The authors suggested that observed effects from infrasound resulted from an impact on the vestibular reflex. Wide octave band noise had no observed effect on eye movement and body sway, although the pulse-wave was changed by exposure. | | | | |
| Waye et al. (2003) | Cross-over design<br>Twelve male subjects slept for 5 consecutive nights in a noise-sleep laboratory.<br>After one night of acclimatisation and one reference night, subjects were exposed to either traffic noise (TN) or low-frequency noise (LFN) on alternate nights. Exposure order was randomised. | TN (35 dB $LA_{eq}$, 50 dB $LA_{max}$) or LFN (40 dB $LA_{eq}$).<br>LFN = frequency range of 31.5–125 Hz.<br>Third octave band at 50 Hz was amplitude modulated with modulation frequency of 2 Hz. | Salivary-free cortisol concentration. Subjects also completed questionnaires on mood and sleep quality. | The authors stated that the study was hypothesis-generating.<br>The exposure conditions were developed to resemble normal sleeping.<br>Exposure represents acute exposure (after one night of acclimatisation) and may not be applicable to the wind turbine setting.<br>There could have been previous exposure and adaptation to TN exposure, whereas the reaction to LFN might have been an alarm reaction. |
| **Results**<br>*Median values of subjective sleep evaluations* | | | | |

| | Reference night | TN | LFN |
|---|---|---|---|
| Response variable[a] | | | |
| Recalled time to fall asleep (min) | 20 | 35 | 39[b] |
| Morning feelings | | | |

| Study | Design | Exposure | Outcome | Limitations |
|---|---|---|---|---|
| Tense | 3.0 | 4.3 | 4.0 | |
| Irritated | 2.8 | 4.6[b] | 4.2 | |
| Afternoon feelings | | | | |
| Tense | 3.1 | 4.0 | 2.6 | |
| Irritated | 2.4 | 2.5 | 2.4 | |
| Evening feelings | | | | |
| Tense | 3.2 | 1.8 | 2.4 | |
| Irritated | 1.9 | 1.6 | 2.4 | |

[a] Subjective variables 'tense' and 'irritated' rated on a 0–10 scale with 10 indicating the highest degree of tension/irritability.

[b] p<0.05 P value for comparison with reference night

*Pearson's correlation coefficients (r) between subjective response and cortisol levels at 30 and 45 minutes*

| | Cortisol level at 30 minutes | | | | Cortisol level at 45 minutes | | | |
|---|---|---|---|---|---|---|---|---|
| | TN | | LFN | | TN | | LFN | |
| | *r* | p value | *r* | p value | *r* | p value | *r* | p value |
| Response variable: | | | | | | | | |
| Sleep quality | –0.66 | <0.05 | –0.34 | >0.10 | –0.55 | 0.06 | –0.31 | >0.10 |
| Morning | | | | | | | | |
| Tiredness | –0.53 | 0.08 | –0.33 | >0.10 | –0.40 | >0.10 | –0.56 | 0.06 |
| Irritation | –0.21 | >0.10 | –0.44 | >0.10 | –0.05 | >0.10 | –0.50 | 0.09 |
| Activity | –0.23 | >0.10 | 0.60 | <0.05 | –0.20 | >0.10 | 0.56 | 0.06 |
| Pleasantness | 0.04 | >0.10 | 0.59 | <0.05 | 0.14 | >0.10 | 0.51 | 0.09 |

**Summary**

Awakening cortisol response on the reference nights showed a normal cortisol pattern (as indicated by the graphical analysis not shown here). Subjects reported that they took longer to fall asleep during exposure to LFN than on reference night. The awakening cortisol response following exposure to LFN was attenuated at

| Study | Design | Exposure | Outcome | Limitations |
|---|---|---|---|---|
| 30 minutes after awakening. Lower cortisol levels after awakening were associated with subjective reports of lower sleep quality and mood. Most notably, levels of cortisol had not peaked by 30 minutes post awakening after exposure to low-frequency noise, and these attenuated levels of cortisol were related to tiredness and negative mood. Exposure to traffic noise was observed to induce 'irritation'. Cortisol levels 30 minutes after awakening were related to sleep quality after exposure to traffic noise. | | | | |
| Waye et al. (2002) | Cross-over study assessing impact of LFN on cortisol in 32 participants. Each participant took part in two test sessions, on separate days and always in the afternoon. Total average exposure time was 2 hours and 10 minutes. Proportion of subjects starting (non-randomised) with each of the two noise conditions was similar, 18/14 for LFN condition and 20/12 for the reference noise condition. | Two noises were used: reference noise (recorded from a ventilation installation, flat frequency); LFN (frequency range of 31.5–125 Hz) plus the ventilation noise, using a digitised sound processor system. | Subjective stress and annoyance; any resultant increase in cortisol secretion; influence of noise sensitivity on cortisol response. | Applicability: study set out to replicate office working conditions and the noises emitted from air-conditioning or ventilation systems. A 2-hour office work task performed in the afternoon may not produce the same effects as continuous exposure to LFN from wind turbines. |

| Study | Design | Exposure | Outcome | Limitations |
|---|---|---|---|---|
| **Results**<br>*ANOVA for a 3-way interaction between salivary cortisol concentration, noise condition and sensitivity category*<br>*F*-statistic p value<br>3.736[a] 0.06[a]<br>[a] The authors reported these data for 'the interaction between noise condition, *time period* and sensitivity'. Professor Persson Waye clarified, upon being contacted, that 'time period' related to 'cortisol concentration over time'.<br>**Summary**<br>Higher cortisol levels (six saliva samples during the 2-hour exposure) were observed among the group with high sensitivity to noise under exposure to LFN (p=0.06). This difference could be due to chance. | | | | |
| Danielsson and Landstrome (2009) | Randomised cross-over trial assessing impact of acute infrasound on blood pressure, pulse rate and serum cortisol levels in 20 healthy male volunteers. | Varying sound frequencies (6, 12, 16 Hz) and pressure levels (95, 110, 125 dB(lin)) were tested. | Diastolic and systolic blood pressure; pulse rate; serum cortisol. | Process of randomisation not adequately described.<br>Applicability of findings from a controlled experimental condition to wind turbine setting uncertain. |

**Results**

*Blood pressure (mmHg) and heart rate (beats/minute) during exposure to 125 dB infrasound at different frequencies and adjacent silent control periods, mean ± SE*

| | Frequency (Hz) | | |
|---|---|---|---|
| | 6 | 12 | 16 |
| Diastolic blood pressure | | | |
| Test | 66.2±2.2 | 65.8±2.2 | 67.3±1.9 |
| Control | 65.9±1.9 | 66.4±2.1 | 66.3±2.3 |
| Difference | 0.3 (p<0.05) | –0.6 (NS) | 1.0 (p=0.05) |

| Study | Design | Exposure | Outcome | Limitations |
|---|---|---|---|---|
| Systolic blood pressure | | | | |
| Test | 118.3±1.6 | 118.9±1.8 | 117.4±1.6 | |
| Control | 119.2±1.7 | 119.0±1.6 | 119.5±1.7 | |
| Difference | –0.9 (NS) | –0.1 (p=0.05) | 2.1 (p<0.01) | |
| Pulse rate | | | | |
| Test | 59.1±1.6 | 59.3±1.9 | 59.2±1.8 | |
| Control | 61.1±1.8 | 60.9±2.0 | 61.0±1.9 | |
| Difference | –2.0 (p<0.01) | –1.6 (p<0.01) | –1.8 (p<0.01) | |
| *Blood pressure (mmHg) and heart rate (beats/min) during exposure to 16 Hz infrasound at different pressure levels and adjacent silent control periods, mean ± SE* | | | | |
| | | Exposure (dB) | | |
| | 95 | 110 | 125 | |
| Diastolic blood pressure | | | | |
| Test | 71.8±1.5 | 70.8±1.5 | 71.3±1.5 | |
| Control | 70.4±1.5 | 70.8±1.5 | 71.8±1.5 | |
| Difference | 1.4 (p<0.05) | 0.0 (NS) | –0.5 (NS) | |
| Systolic blood pressure | | | | |
| Test | 123±1.8 | 121.4±1.5 | 122.8±1.6 | |
| Control | 122.8±1.8 | 121.6±1.6 | 122.4±1.7 | |
| Difference | –0.5 (NS) | –0.2 (NS) | 0.4 (NS) | |
| Pulse rate | | | | |
| Test | 60.5±2.5 | 60.0±2.3 | 60.9±2.4 | |
| Control | 61.1±2.4 | 61.2±2.4 | 60.8±2.3 | |
| Difference | –0.6 (NS) | –1.2 (p<0.01) | 0.1 (NS) | |

| Study | Design | Exposure | Outcome | Limitations |
|---|---|---|---|---|
| **Summary**<br>The data suggest statistically significant, albeit very small and inconsistent, changes in systolic and diastolic blood pressure and pulse rate. The authors note that acute infrasonic stimulation induces a peripheral vasoconstriction with increased blood pressure. There was no statistically significant change in serum cortisol levels (no data provided by authors). | | | | |
| Alford et al. (1966) | Pre-post test design assessing impact of laboratory-induced LFN on extra-auditory function in 21 subjects. | 3 minutes of repeated exposure to 119–144 dB / 2–12 Hz. | Temporary threshold shift (TTS)[a]; breathing rate; nystagmus; vertigo; reaction performance time.<br>[a] Exposure to impulse and continuous noise may cause only a temporary hearing loss. If a person regains hearing, the temporary hearing loss is called a temporary threshold shift. | The number of subjects was small.<br>5 subjects in the case series had some form of hearing loss.<br>There was no control group. |
| **Results**<br>The data showed TTS from 10 dB to 22 dB in 11 of 21 subjects after 3 minutes of repeated exposure to 119–144 dB / 2–12 Hz. The TTS was observed in the frequency range 3–8 kHz. There was a slight increase in breathing rate (4 breaths/minute). There were no effects of LFN on nystagmus, vertigo (vestibular effects), reaction performance time and heart rate. None of the subjects reported respiratory distress, palpitations or abdominal cramps. All subjects reported experiencing some pressure in their ears but only one reported tinnitus. No discomfort was experienced with regard to bodily vibration, disorientation, mental confusion, sensory decrement or post-exposure fatigue. | | | | |
| Mills et al. (1983) | Pre-post test design examining impact of LFN on TTS in 52 subjects. | Subjects were exposed for 8 hours (SPL=90 dB(A)) or 24 hours (SPL=84 dB(A)) to an octave-band noise centred at 63, 125 or 250 Hz. | TTS | There are inadequate data presented in the paper to assess the validity of this study. |

| Study | Design | Exposure | Outcome | Limitations |
|---|---|---|---|---|
| **Results**<br>Only an abstract was available.<br>**Summary**<br>TTSs of different degrees were observed depending on the frequency of the noise (octave-band noise, centred at 63, 125 or 250 Hz). After 24 hours of exposure to 84 dB(A), TTS from 7 dB to 15 dB in the frequency range 300–500 Hz was observed. An 8-hour-exposure to 90 dB(A) caused TTS from 12 dB to 17 dB in the frequency range 25–700 Hz. Although TTS was less than 20 dB, complete recovery for many of the subjects required as long as 48 hours. | | | | |

Abbreviations: RCT = randomised controlled trial; ILFN = infrasound and low-frequency noise; SPL = sound pressure level; TN = traffic noise; TTS = temporary threshold shift; ANOVA = analysis of variance; SE = standard error; dB = decibels; dB(A) = A-weighted sound pressure level (decibels); dB(lin) = unweighted sound pressure level (decibels); NS = not (statistically) significant

## SUMMARY: MECHANISTIC AND PARALLEL EVIDENCE ON NOISE

### *BQ1. What are wind turbines and wind farms?*

A wind turbine uses wind to produce electricity. There are two main types of wind turbine: the horizontal axis wind turbine (HAWT) and the vertical axis wind turbine (VAWT). HAWTs are more common because they are considered to be more efficient (Ali et al. 2011).

A group of wind turbines is known as a wind farm. A large wind farm may consist of several hundred individual wind turbines, cover a large geographical area and be located offshore or on land.

### *BQ2. By what specific physical emissions might wind turbines cause adverse health effects? (Noise)*

Noise is defined as an unwanted sound or an unwanted combination of sounds. Sound is perceived and recognised by its loudness (sound pressure level, SPL) and pitch (frequency). The general range for human hearing for young adults is between 20 Hz and 20 kHz, with a declining upper limit with ageing (Berglund, Hassmen & Job 1996). Low-frequency sound definitions vary and can range from 20 Hz up to 100 Hz - 250 Hz. Sound <20 Hz is generally termed infrasound and is considered inaudible in normal environments. However, frequencies well below 20 Hz can be audible if the amplitude of the SPL is high enough.

Aerodynamic noise is the major component of noise from modern wind turbines (Pedersen & Persson Waye 2004, 2007; van den Berg 2004). A key source of aerodynamic sound from modern wind turbines is the trailing edge noise that originates from air flow around the components of the wind turbine (blades and tower), producing a 'whooshing' sound in the 500–1000 Hz range (Hau 2008; Roberts & Roberts 2009). This is often described as amplitude (or aerodynamic) modulation, meaning that the sound can vary due to atmospheric effects and directional propagation effects (van den Berg 2004).

**SUMMARY (Cont.)**

*BQ3. For each such emission, what is the level of exposure from a wind turbine and how does it vary by distance and characteristics of the terrain separating a wind turbine from potentially exposed people?*

Numerous factors (e.g. meteorological conditions, wind turbine spacing, wake and turbulence effects, vortex effects, turbine synchronicity, tower height, blade length and power settings) can contribute to the wind turbine sound that is heard or perceived at residences. However, consistent with the inverse distance law, most wind turbine sound will dissipate as distance from the source increases.

Noise at high frequency lessens in intensity (loudness as measured by SPL) over much shorter distances than noise at lower frequency. It does not pass easily through doors and windows—unlike lower frequencies which can more easily pass through these obstacles. ILFN is, therefore, the exposure of most relevance at the range of distances typically observed between residential dwellings and commercial wind turbines. Hearing becomes gradually less sensitive as frequency decreases, so for humans to perceive ILFN, the SPL needs to be high.

Deriving a specific SPL from wind turbines in the presence of background noise is difficult. The 2013 South Australian EPA study (Evans, Cooper & Lenchine 2013) measured infrasound at urban and rural locations and compared these with measurements taken at residences near two wind farms. Levels of background noise at residences near the wind farms were also measured during organised turbine shutdowns. It was concluded that the level of infrasound at locations near wind farms was no greater than that experienced in other urban and rural environments. Further, the contribution of wind turbines to the measured infrasound levels taken at residences at a distance of approximately 1.5 km was insignificant in comparison with the background level of infrasound in the environment.

**SUMMARY (Cont.)**

*BQ4. Is there basic biological evidence, or evidence from research into other circumstances of human exposure to physical emissions that wind turbines produce, that make it plausible that wind turbines cause adverse health effects?*

The health effects of noise within the audible range, particularly from road traffic, are well known. However, extrapolation of these findings to the wind farm context is not simple. Given that distance is highly correlated with estimated SPL, it is not expected that substantial audible noise exposures (>45 dB(A)) would be associated with modern wind turbines at distances of more than about 280 m (Ellenbogen et al. 2012), although this might vary by terrain, type of wind turbine and wind conditions. Sleep disturbance from noise exposure alone is not plausible at noise levels of 30 dB(A) and below, and has only modest effects at 40 db(A) and below (WHO 2011).

ILFN produced in the laboratory setting—with SPL typically greater than 80 dB but ranging between 40 and 144 dB in the available studies—appeared to have inconsistent and inconclusive physiological effects. Outcomes that were considered in these laboratory studies included changes in heart rate, cortisol level, respiratory rate and blood pressure. The data suggest that low-frequency noise at high SPLs may elicit a temporary threshold shift in hearing (Alford et al. 1966; Mills et al. 1983) and may lead to statistically significant, albeit very small and inconsistent, changes in systolic and diastolic blood pressure, and pulse or heart rate. Health outcomes were not studied. There were too few studies reporting on exactly the same intervention or outcomes to determine if the results were replicable, and where studies were similarly designed there were inconsistent findings with respect to whether or not ILFN influenced physiological measures.

# SHADOW FLICKER

*BQ2. BY WHAT SPECIFIC PHYSICAL EMISSIONS MIGHT WIND TURBINES CAUSE ADVERSE HEALTH EFFECTS?*

## Predicting the extent of shadow flicker from a wind turbine

Exposure to flicker from a turbine is determined by the hub height, blade diameter, height of the sun and blade direction relative to the observer, and these variables are affected by the time of day, time of year, wind direction and geographical location (Harding, Harding & Wilkins 2008; Verkuijlen & Westra 1984).

Ellenbogen et al. (2012) present a detailed discussion of how to estimate the maximum distance from a wind turbine that a shadow flicker will extend to. Briefly, this can be estimated using the following formula:

$$X_{shadow,\,max} = (H + R - h_{view})/\tan(\alpha_s)$$

where $H$ is the turbine height, $R$ is the rotor radius, $h_{view}$ is the height of the viewing point and $\alpha_s$ is the altitude of the sun.

Ellenbogen et al. (2012) report that 'safe distances to reduce shadow flicker' would depend on the specific nature of the project and the presence of residences or roadways and geographic layout. Forestry and existing shadows would diminish the nuisance from turbine-produced shadow flicker, whereas open-land areas (such as farmland) are more susceptible to flicker-induced annoyance.

Generally, a shadow flicker 'risk zone' would incorporate an impact area that is 10-fold the turbine rotor diameter[38]. Only certain areas of the impact would be exposed to shadow flicker *for a significant amount of time*. The NEWEEP Webinar[39] gives a detailed discussion of the methodologies involved in forecasting time, place and extent of shadow flicker; the potential impact on residences in proximity to the shadow flicker; and proposed mitigation and management practices.

*BQ3. WHAT IS THE LEVEL OF FLICKER EXPOSURE FROM A WIND TURBINE AND HOW DOES IT VARY BY DISTANCE AND CHARACTERISTICS OF THE TERRAIN SEPARATING THE WIND TURBINE FROM POTENTIALLY EXPOSED PEOPLE?*

The timing, intensity and location of shadow flicker are influenced by turbine size and shape, landscape features, latitude, weather and wind farm layout. Reviews by Harding, Harding and Wilkins (2008), Verkuijlen et al. (1984) and Rideout, Copes and Bos (2010) provide guidance on the design of wind farms in order to reduce the risk of flicker-induced seizure, as summarised below:

- Shadow flicker wind turbines should only be installed if flicker frequency is maintained below 2.5 Hz, under all conditions. Turbine blades should be programmed to stop when blade rotation

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[38] Thus the risk zone for a 90-m rotor diameter would be equivalent to a 900-m impact area.

[39] <http://www.windpoweringamerica.gov/filter_detail.asp?itemid=2967>

exceeds 3 Hz (60 rpm for a three-blade turbine). Most industrial turbines operate between 30 and 60 rpm.

- The layout of wind farms should ensure that shadows cast by one turbine upon another should not be readily visible to the general public. The shadows should not fall upon the windows of nearby buildings. The reflection from turbine blades should be minimised.
- Wind farms should be placed at a distance sufficient to reduce contrast; that is the degree of sunlight occlusion by turbine blades. According to Harding, Harding and Wilkins (2008), assuming that contrasts of less than 10% occur when the width of the turbine blade subtends at the eye an angle that is 10% of the sun's diameter (0.05 degrees), it is possible to set a limit for the distance at which shadow flicker is likely to be seizure provoking. For a turbine blade that is 1 m in diameter, this distance is 1.14 km (Harding, Harding & Wilkins 2008).
- The resulting flicker frequency, from a combination of blades when several turbines are aligned with the sun's shadow, could be higher than that from a single turbine. If the blades of a turbine are reflective, there is the possibility of flicker from reflected light at viewing positions that are unaffected by shadows.

## Frequency thresholds and seizure risk from shadow flicker or blade glint

The Institute of Electrical and Electronics Engineers suggest that the health effects of flicker can be categorised into those that are immediate (effects resulting from a few seconds' exposure, such as epileptic seizures) and those that take time to develop (effects resulting from long-term exposure such as malaise, headaches and impaired visual performance). Epileptic seizures are associated with visible flicker, typically within the range 3–70 Hz, while human biologic effects due to invisible flicker (that which is not consciously perceivable by a human viewer) occur at frequencies above those at which flicker is visible but at <165 Hz (Wilkins, Veitch & Lehman 2010). Seizures induced by visual or photic stimuli are usually observed in individuals with certain types of epilepsy, particularly generalised epilepsy (Guerrini & Genton 2004). Approximately 3% of people with epilepsy are photosensitive (Rideout, Copes and Bos 2010).

In normal human physiology, millions of tiny electrical charges are relayed from nerve cells in the brain to all parts of the body. However, in patients with epilepsy there is a sudden and unusual interruption of this conduction process by intense bursts of electrical energy. This can temporarily affect a person's consciousness, bodily movements and sensation (NINDS 2012). Approximately 1 in 4000 individuals has photosensitive epilepsy. It is typically five times more common around puberty (age range 7–20 years) than in the general population. Photosensitive epilepsy can be induced by 'repetitive flashing lights' and 'static repetitive geometric patterns', with the flicker inducing transient abnormal synchronised activity of brain cells, affecting consciousness, bodily movements or sensation. However, the likelihood of a seizure depends on the location of stimulation within the visual field. Stimulation of central vision poses a higher risk of a seizure compared with stimulation of the visual periphery, although the latter may be more distinctive (Wilkins, Veitch & Lehman 2010).

The Wisconsin Wind Siting Council notes that there is some evidence that the interruption of sunlight by helicopter blades has caused seizures, and that there have been two unconfirmed reports of seizures due to shadow flicker (McFadden 2010).

Aspects of flicker that pose a seizure risk include:

- flash frequency in a frequency range 3–70 Hz (Harding, Harding & Wilkins 2008; Verkuijlen & Westra 1984; Wilkins, Veitch & Lehman 2010), with the greatest likelihood of seizures occurring at the frequency range 15–20 Hz
- brightness—stimulation in the scotopic or low mesopic range (<1 candela or $cd/m^2$) has a low risk, while there is a monotonic increase in risk with log luminance in the high mesopic and photopic range
- contrast with background lighting, such as the sun—contrasts above 10% are considered a potential risk (Harding, Harding & Wilkins 2008).

The risk of seizures from wind turbines in individuals with a risk of photosensitive epilepsy can be determined by modelling the light–dark contrasts of turbine shadows for worst case conditions, that is, a completely cloud-free atmosphere, with blade rotation in the vertical plane and on a line between the observer and the sun, directly facing the observer (Smedley, Webb & Wilkins 2009). The authors conclude that there is no evidence of epileptogenic risk to observers looking towards the horizon except when standing closer than 1.2 times the total turbine height on land (or closer than 2.8 times the total turbine height for marine environments). In addition, given the tendency of photosensitive individuals is to stare away from the sun (except when in a shadow zone), for an observer viewing the ground, the contrast is almost always insufficient to be epileptogenic. Finally, the authors suggest that large turbines are unlikely to rotate fast enough to induce seizures (<3 Hz, the lower frequency threshold at which seizures are a potential risk). The rotation frequency increases inversely with the blade length; thus, smaller micro-generation turbines are more likely to induce seizures if the intensity and stimulus conditions are met.

The Environment Protection and Heritage Council of Australia (EPHC; 2010) notes that the risk of seizures from modern wind turbines is negligible, given that less than 0.5% of the population are subject to epilepsy at any point in time and, of this proportion, 5% are vulnerable to strobe lighting (light flashes). In the majority of circumstances (>95% of the time), the frequency threshold for individuals susceptible to strobe lighting is >8 Hz, with the remainder affected by frequencies >2.5 Hz. The EPHC estimates that the probability of conventional horizontal-axis wind turbines causing an epileptic seizure for an individual experiencing shadow flicker is <1 in 10 million in the general population. They further indicate that blades from modern wind turbines are now treated with low-reflective coating that prevents glint from the blade surface, and thus the risk of blade glint is considered very low.

Harding, Harding and Wilkins (2008) and Verkuijlen et al. (1984) report that the shadow flicker frequencies of modern conventional horizontal-axis wind turbines are ≤1 Hz. Ellenbogen et al. (2012) support this view, indicating that shadow flicker emitted from wind turbines is usually in the range 0.3–1.0 Hz, which is well below the frequencies associated with seizure risk. The authors also note that frequency of shadow flicker emitted from wind turbines is proportional to the rotational speed of the rotor multiplied by the number of blades; for large wind turbines these are typically in the range 0.5–1.1 Hz. Harding, Harding and Wilkins (2008) report that the cumulative risk of inducing a seizure at ≤3 Hz is approximately 1.7 per 100,000 *in a photosensitive population* (1.7 per 400 million persons in general).

McFadden et al. (2010) propose that shadow flicker is primarily an issue of annoyance at typical wind turbine frequencies (0.6–1.0 Hz). This is supported by Rideout, Copes and Bos (2010), who note that there is evidence that annoyance was more closely associated with whether shadow flicker occurred when people were at home, rather than with the duration of the exposure.

## Systematic literature review

### *SQ4. IS THERE ANY RELIABLE EVIDENCE OF AN ASSOCIATION BETWEEN SHADOW FLICKER (PHOTOSENSITIVITY GREATER THAN 3 HZ) FROM WIND TURBINES AND ADVERSE HEALTH EFFECTS?*

No studies reported on the health effects of shadow flicker from wind turbines. One Australian cross-sectional study with poor reporting provided information on the rates of annoyance from flickering in homes within 5 km and 10 km from Waterloo wind farm (Morris 2012). A summary of the study characteristics is in Table 31.

Table 31 Profile of one study assessing shadow flicker

| Study | Design/ Sample | Exposure | Outcome measure | Other factors that may influence results |
|---|---|---|---|---|
| Morris (2012)<br><br>Mt Lofty Ranges, Australia | Cross-sectional anonymous self-reporting survey.<br><br>n=93 households<br><br>Non-standardised survey developed by the authors.<br><br>Intent of survey not masked from participants. | Households within 10 km of Waterloo Wind Farm, North Mount Lofty Ranges, South Australia.<br><br>Subgroups within 0–5 km and 5–10 km. | Anyone in the household annoyed by flickering | Confounders<br>Unclear as very little information was reported on participant or household characteristics or pre-existing health conditions.<br><br>Bias<br>Sample selection bias cannot be excluded as the response rate was only 40% of households surveyed (0–10 km; 55% for 0–5 km). No masking of study intent may have resulted in recall bias. Differential participation rates by distance (selection bias).<br><br>Chance<br>No formal statistical tests of association were conducted. |

Sufficient information was provided in the paper to calculate the odds of annoyance in respondents living within 5 km, and those living between 5 and 10 km, from the nearest wind turbine. Those living within 5 km of a wind turbine had over five times the odds of being annoyed by shadow flickering in their home than those who lived between 5 and 10 km away. Respondents claimed that flicker was annoying, distracting, and caused headaches and blurred vision (Table 32).

No adjustments were (or could have been) made to the results for differences between distance categories for age, gender, financial benefit from wind turbines, attitudes towards wind turbines in general or attitudes towards the visual impact of wind turbines on the landscape. It is therefore unknown whether any of these possibly confounding factors could have influenced the results. Selection bias could easily have affected the results since only 55% of those living within 5 km, and 34% of those living between 5 and 10 km responded to the survey and study intent was not masked.

Table 32 Association between distance from wind turbine and annoyance at shadow flicker

| **Study** | **Outcome measure** | **Distance from nearest industrial wind turbine** | | **OR (95%CI)** |
|---|---|---|---|---|
| | | **0–5 km (n=41)** | **5–10 km (n=52)** | |
| Morris (2012) Australia | Annoyance at flicker in home | 7/41 (17.1%) | 2/52 (3.8%) | **5.14 (1.01, 26.29)** |

**Bolded values indicate statistically significant differences.**
Abbreviations: OR = odds ratio; CI = confidence interval

**SUMMARY: DIRECT EVIDENCE ON SHADOW FLICKER**

*SQ4. Is there any reliable evidence of an association between shadow flicker from wind turbines and adverse health effects?*

One small Australian study found that shadow flicker was more likely to annoy a household member with increasing proximity of a household to a wind farm. Bias and confounding cannot be excluded as possible explanations for this finding.

An assessment of the body evidence addressing this question is given in Box 4.

## Box 4 Evidence statement matrix for shadow flicker

| | | |
|---|---|---|
| **Key question:**<br>Is there any reliable evidence of an association between **shadow flicker** from wind turbines and adverse health effects? If so:<br>**A.** How strong is this association?<br>**B.** How does the strength of this association relate to *distance* from wind turbines? *[Systematic Review question on distance has been merged here]*<br>**C.** Might this association be explained by:<br>i. chance?<br>ii. bias? or<br>iii. confounding? | | **Morris (2012)** |
| **1. Evidence-base** *(Number of studies, level of evidence, and risk of bias and confounding in the included studies)* | | |
| 1 level IV study (cross-sectional study) at high risk of bias and confounding | A | One or more level I studies with a low risk of bias or several level II studies with a low risk of bias and confounding |
| | B | One or two level II studies with a low risk of bias or SR/several level III studies with a low risk of bias and confounding |
| | C | One or two level III studies with a low risk of bias or level I or II studies with a moderate risk of bias and confounding |
| | D | Level IV studies or level I to III studies/SRs with a high risk of bias and confounding |
| **2. Consistency** *(If only one study was available, rank this component as 'not applicable')* | | |
| Only one study | A | All studies consistent |
| | B | Most studies consistent and inconsistency can be explained |
| | C | Some inconsistency, reflecting genuine uncertainty around question |
| | D | Evidence is inconsistent |
| | NA | Not applicable (one study only) |
| **3. Population health impact** *(Indicate in the blank space below if the study results varied according to some unknown factor (not simply study quality or sample size) and thus the population health impact of the exposure could not be determined; or whether the impact could not be determined because the studies were underpowered and could not be meta-analysed. Otherwise, provide justification for your selection of the A–D rating, i.e. the size of the effect and precision of the estimate of adverse health effects)* | | |
| One small Australian study reported found that shadow flicker was more likely to annoy a household member with increasing proximity of a household to a wind farm (17.1% at 0-5km and 3.8% at 5-10km). While bias and confounding could explain this finding, if true, shadow | A | Very large |
| | B | Substantial |

| | | |
|---|---|---|
| flicker would have a moderate impact on annoyance in the exposed population. Annoyance, though, is not a health effect | C | Moderate— for other relevant non-health effect (annoyance) |
| | D | Unknown—for health effects |
| **4. Generalisability** *(How well does the body of evidence match the population being targeted by the NHMRC advice?)* | | |
| The generalisability of the study is limited, given the poor response rates. No sample characteristics provided. | A | Evidence directly generalisable to target population |
| | B | Evidence directly generalisable to target population with some caveats |
| | C | Evidence not directly generalisable to the target population but could be sensibly applied |
| | D | Evidence not directly generalisable to target population and hard to judge whether it is sensible to apply |
| **5. Applicability** *(Is the body of evidence relevant to the Australian setting for the exposure?)* | | |
| The study was based in Australia. | A | Evidence directly applicable to Australian exposure setting |
| | B | Evidence applicable to Australian healthcare exposure setting with few caveats |
| | C | Evidence probably applicable to Australian exposure setting with some caveats |
| | D | Evidence not applicable to Australian exposure setting |

**Other factors** *(Indicate here any other factors that you took into account when assessing the evidence-base (e.g. issues that might cause the group to downgrade or upgrade the recommendation, such as the biological plausibility evidence presented in Background Question 4)*

The information addressing Background Questions 3 and 4 (see relevant sections of the report) was not sufficiently persuasive to result in an upgrade of the evidence rating obtained from the direct evidence. A mechanism of action for shadow flicker to cause adverse health effects was identified (in individuals with photosensitive epilepsy–a very rare condition in the general population) but it was unclear whether the shadow flicker produced by wind turbines would produce seizures. The shadow flicker investigated in laboratory circumstances was of a different type than that produced by wind turbines.

The quality of the evidence-base and lack of any evidence relating to direct health effects was given greatest weight when formulating the overall rating.

**EVIDENCE STATEMENT MATRIX**

*Please summarise the synthesis of the evidence relating to the key question, taking all the above factors into account.*

| Component | Rating | Description |
|---|---|---|
| **1. Evidence-base** | D | One cross-sectional study with high risk of bias |
| **2. Consistency** | NA | NA (one study only) |

| | | |
|---|---|---|
| *3.* **Population health impact** | D<br>/<br>C | Unknown—for health effects<br><br>Moderate— for other relevant non-health effect (annoyance) |
| **4. Generalisability** | C | Evidence not directly generalisable to the target population but could be sensibly applied |
| **5. Applicability** | A | Evidence directly applicable to Australian exposure setting |

| *Evidence statement* | *Evidence rating* |
|---|---|
| No studies reliably assessed whether shadow flicker is associated with health outcomes. One small Australian study of at high risk of bias and confounding reported that shadow flicker was more likely to annoy a household member with increasing proximity of households to a wind farm. | D |

## Parallel evidence

*BQ4. IS THERE BASIC BIOLOGICAL EVIDENCE, OR EVIDENCE FROM RESEARCH INTO OTHER CIRCUMSTANCES OF HUMAN EXPOSURE TO FLICKER, THAT MAKE IT PLAUSIBLE THAT WIND TURBINES CAUSE ADVERSE HEALTH EFFECTS?*

The parallel evidence identified for Background Question 4 concerning the effects of shadow flicker on human health is summarised in Table 33. This evidence was used to address the biological plausibility that wind farms could cause adverse health effects. The specific limitations of each of the studies are also provided.

One small RCT (Pohl, Faul & Mausfeld 1999) and a small prospective cohort study (Shirakawa et al. 2001) recruited subjects to participate in experimental conditions simulating flicker. Pohl and colleagues considered a range of stress-related outcomes but found no differences between the exposed group (60 minutes of simulated shadow flicker) and the control group (conditions under the same lighting but without flicker). The applicability of this study in the context of wind farms is uncertain as the frequencies used in the flicker experiments were not stated. Shirakawa et al. reported on photoparoxysmal response to a range of frequencies relevant to flicker from wind turbines (>3 Hz). However, flicker exposure was via a television medium (coloured light) and *only photosensitive individuals* were included as participants. Therefore, its results are of uncertain relevance to shadow flicker associated with wind turbines.

## Table 33 Parallel evidence examining the association between shadow flicker and adverse health effects

| Study | Design | Exposure | Outcomes | Limitations |
|---|---|---|---|---|
| Pohl, Faul and Mausfeld (1999)<br>German government-sponsored study | RCT<br>2 groups of males and females: Group 1, 32 students (mean age = 23 years); Group 2, 25 professionals (mean age = 47 years)<br>Each group randomly assigned to either 60 minutes of simulated flicker (experimental group) or similar lighting conditions without periodic shadow or flicker.<br>Study consisted of 6 test and measurement phases: 2 before the light was turned on; 3 at intervals of 20 minutes while simulated flicker or the control condition was in progress; 1 after simulated flicker was turned off. | 60 minutes of simulated flicker. | Stress-related health effects: general performance stress indicators (arithmetic, visual search tasks); mental and physical wellbeing; cognitive processing; and stress in the autonomic nervous system (heart rate, blood pressure, skin conductance and finger temperature). | There were inadequate data presented in the review by Ellenbogen et al. (2012), which included this study. Pohl, Faul and Mausfeld (1999) were published in German and were not translated because an inclusion criterion for BQ4 was English literature only. |
| **Results**<br>Only a short narrative summary of results was included in the review by Ellenbogen et al. (2012). The original article by Pohl, Faul and Mausfeld (1999) was in | | | | |

<table>
<tr><th>Study</th><th>Design</th><th>Exposure</th><th>Outcomes</th><th>Limitations</th></tr>
<tr><td colspan="5">German.<br>Summary<br>Systemic effects were comparable across groups. On the results of this study, Ellenbogen et al. (2012) note that ‘there is limited evidence primarily from a study by Pohl, Faul and Mausfeld (1999) that prolonged shadow flicker (more than 30 minutes) can result in transient stress-related effects on cognition (concentration, attention) and autonomic nervous system functioning (heart rate, blood pressure)’.</td></tr>
<tr><td>Shirakawa et al. (2001)</td><td>Non-randomised provocation study comparing multiple groups with varying levels of colour flicker at varying frequencies.<br>All subjects were photosensitive (n=35).</td><td>Rates of photoparoxysmal response (PPR) provocation.</td><td></td><td>The study examined photosensitive individuals—20/35 (57%) were being treated with antiepileptic drugs. It is not known what proportions of residents living near wind turbines are photosensitive.<br>The exposures were colour related to mimic flicker emitted from a television. It is difficult to apply these results to the wind turbine flicker setting.<br>Potential for observer bias given the lack of concealment of allocation.</td></tr>
<tr><td colspan="5">Results<br>Proportions of individuals experiencing PPR provocation at 3, 10, 20 and 30 Hz among the 35 subjects
<table>
<tr><th></th><th colspan="4">Frequency</th></tr>
<tr><th></th><th>3 Hz</th><th>10 Hz</th><th>20 Hz</th><th>30 Hz</th></tr>
<tr><td>Subjects with PPR provocation, %</td><td>5.7</td><td>28.6</td><td>22.9</td><td>28.6</td></tr>
</table>
Summary<br>The PPR provocation rates at 10, 20, and 30 Hz were significantly greater than at 3 Hz (p<0.01 for all comparisons).</td></tr>
</table>

Abbreviations: RCT = randomised controlled trial; PPR = photoparoxysmal response; Hz = hertz

## SUMMARY: MECHANISTIC AND PARALLEL EVIDENCE ON SHADOW FLICKER

*BQ2. By what specific physical emissions might wind turbines cause adverse health effects? (Shadow Flicker)*

Shadow flicker occurs as turbine blades pass before the sun and create shadows. Exposure to flicker from a turbine is determined by the hub height, blade diameter, height of the sun and blade direction relative to the observer, and these variables are affected by the time of day, time of year, wind direction and geographical location (Harding, Harding & Wilkins 2008; Verkuijlen & Westra 1984).

It is well recognised that shadow flicker exposure can affect health by inducing seizures in those prone to photosensitive epilepsy. This very rare condition can be induced by repetitive flashing lights and static repetitive geometric patterns, with the flicker inducing transient abnormal synchronised activity of brain cells and affecting consciousness, bodily movements and/or sensation.

*BQ3. For each such emission, what is the level of exposure from a wind turbine and how does it vary by distance and characteristics of the terrain separating a wind turbine from potentially exposed people?*

The timing, intensity and location of shadow flicker are influenced by turbine size and shape, landscape features, latitude, weather and wind farm layout. 'Safe distances to reduce shadow flicker' would depend on the specific nature of the project and the presence of residences or roadways and geographic layout. Forestry and existing shadows would diminish the nuisance from turbine-produced shadow flicker, whereas open-land areas (such as farmland) are more susceptible to flicker-induced annoyance. Generally, a shadow flicker 'risk zone' would incorporate an impact area that is 10-fold the turbine rotor diameter. Only certain areas of the impact would be exposed to shadow flicker for a significant amount of time. The frequency of shadow flicker emitted from wind turbines is proportional to the rotational speed of the rotor multiplied by the number of blades; for large wind turbines these are typically in the range 0.5–1.1 Hz.

The Environment Protection and Heritage Council of Australia (EPHC; 2010) note that the risk of seizures from modern wind turbines is negligible, given that less than 0.5% of the population are subject to epilepsy at any point in time and, of this proportion, 5% are vulnerable to strobe lighting (light flashes). In the majority of circumstances (>95% of the time), the frequency threshold for individuals susceptible to strobe lighting is >8 Hz, with the remainder affected by frequencies >2.5 Hz. Wind turbine flicker is usually below 1 Hz. The EPHC estimates that the probability of conventional horizontal-axis wind turbines causing an epileptic seizure for an individual experiencing shadow flicker is <1 in 10 million in the general population.

## SUMMARY (CONT.)

*BQ4. Is there basic biological evidence, or evidence from research into other circumstances of human exposure to physical emissions that wind turbines produce, that make it plausible that wind turbines cause adverse health effects?*

Epileptic seizures are associated with visible flicker, typically within the range 3–70 Hz, while human biologic effects due to invisible flicker (that which is not consciously perceivable by a human viewer) occur at frequencies above those at which flicker is visible but at <165 Hz (Wilkins, Veitch & Lehman 2010).

The sparse laboratory evidence available investigating the association between shadow flicker and health outcomes was of uncertain applicability to the shadow flicker conditions produced by wind turbines. One study found no difference in stress-related outcomes between groups exposed and not exposed to shadow flicker but it could not be determined whether the flicker frequencies investigated were similar to those produced by wind turbines (Pohl, Faul & Mausfeld 1999). The other study found photoparoxysmal responses to a range of frequencies relevant to the flicker produced by wind turbines (>3 Hz) but the flicker exposure involved coloured light, rather than shadow, and all of the participants were photosensitive individuals (Shirakawa et al. 2001).

# ELECTROMAGNETIC RADIATION

## *BQ2. BY WHAT SPECIFIC PHYSICAL EMISSIONS MIGHT WIND TURBINES CAUSE ADVERSE HEALTH EFFECTS?*

Electromagnetic radiation (EMR; X-rays, ultraviolet rays, visible light, infrared rays and radio waves) consists of electric and magnetic energy that is transmitted in a wavelike pattern. Magnetic fields (MF) occur where any electric conductor has an electrical current flowing through it. Humans are continuously exposed to time-varying low-frequency EMFs from natural sources (solar activity, earth and human body magnetic fields) (Ahlbom et al. 2001), radio and TV transmission devices, electrical power lines and wiring, and electrical appliances (Ahlbom et al. 2001; EPHC 2010; Rideout, Copes and Bos et al. 2010). Three types of EMF commonly present in the environment are (WHO 2012c):

- extremely low-frequency electromagnetic fields (ELFs) (range <300 Hz)
- intermediate frequency fields (range 300 Hz to 10 MHz)
- radiofrequency fields (range 10 MHz to 300 GHz).

Electrical currents are a vital part of normal bodily function. Biochemical mechanisms and nerve transmission utilise electric impulses. The impact of external exposure to EMF on the human body and its cells depends mainly on the EMF frequency and magnitude or strength (WHO 2002). The frequency (Hz) is the number of oscillations or cycles per second.

Concerns regarding the safety of EMF increased with the publication of an early study in which an association was observed between the risk of childhood leukaemia and the degree of EMF radiation exposure from electricity transmission lines (Wertheimer & Leeper 1979). Further research has been conducted on adults regarding possible occupational EMF associations with cancer, cardiovascular, neurological, psychological and reproductive conditions.

ELF refers to the electromagnetic radiation produced by the flow of electrical current. Examples of sources are electrical distribution cables and electrical equipment, including household appliances. ELFs are also produced by wind turbines, specifically by the grid connection lines, turbine generators, electrical transformers and underground collector network cabling. Rideout, Copes and Bos (2010) note that grid connection lines generate ELF levels that are comparable to those emitted from household appliances. For this reason, ELF is the focus of this review and no further consideration is given to EMF in the intermediate and radiofrequency ranges.

ELF can penetrate the human body and induce electrical currents inside the body. Radio frequency EMF penetrates only a short depth into the tissue and does not induce currents. The induced current strength or magnitude is influenced by the intensity of the outside magnetic field and the size of the loop through which the current flows. Sufficiently large currents can cause stimulation of nerves and muscles (HPA 2012; ICNIRP 2012; NIEHS 2012; WHO 2012a).

### *BQ3. WHAT IS THE LEVEL OF EMR EXPOSURE FROM A WIND TURBINE, AND HOW DOES IT VARY BY DISTANCE AND CHARACTERISTICS OF THE TERRAIN SEPARATING A WIND TURBINE FROM POTENTIALLY EXPOSED PEOPLE?*

## Levels of EMF emitted from wind turbines

For wind farms, EMF is emitted from grid connection lines, underground collector network cabling, electrical transformers and turbine generators. Rideout, Copes and Bos (2010) note that grid connection lines generate low levels of EMF that are comparable to those emitted from household appliances. Underground cables effectively generate no EMF at the surface because of positioning of phase conductors and screening of cables, whereas transformers generate the highest EMF levels. The authors also noted that turbine generators are around 60–100 m above ground level and so there is little or negligible EMF at ground level.

Magnetic field measurements, conducted by Windrush Energy from Windrush wind turbines, were 0.4 mG (milligauss[40]) or 0.04 µT (microtesla) in front of a turbine door, with typical values in the vicinity of wind turbines of 0.004 µT (Windrush Energy 2004). The acceptable EMF health threshold is 83.3 µT (Ahlbom et al. 2001). Windrush indicate that the EMF level emitted from a 2-MW wind turbine set back at 550 m is approximately 12 times less than the EMF exposure of a driver and front seat passenger sitting approximately 1.5 m from the average car alternator. The exposure is also analogous to a hand-held household hair dryer (Windrush Energy 2004).

Table 34 summarises typical magnetic field strengths for different household appliances at various distances. The magnetic field strength of the majority of household appliances at a distance of 30 cm is well below the guideline limit for the general public of 100 µT (WHO 2012b). A World Health Organization report on EMF and health concluded that magnetic field strength rapidly decreases as distance from the appliance increases. For the majority of household appliances that are not operated very close to the body (at a distance of 30 cm), the surrounding magnetic fields are 100 times *lower* than the guideline limit of 100 µT at 50 Hz (83 µT at 60 Hz) for the general public. Thus, if human exposure to EMF from wind turbines is considered to be of similar strength to that emitted by household appliances, these conclusions would have similar applicability.

[40] Milligauss and microtesla (µT) are units for magnetic field strength in common usage; 10 mG = 1 µT.

Table 34 Typical magnetic field strength of household appliances at various distances

| Electric appliance | 3 cm distance (μT) | 30 cm distance (μT) | 1 m distance (μT) |
|---|---|---|---|
| Hair dryer | **6–2000** | 0.01–7 | 0.01–0.03 |
| Electric shaver | **15–1500** | 0.08–9 | 0.01–0.03 |
| Vacuum cleaner | 200–800 | **2–20** | 0.13–2.00 |
| Fluorescent light | 40–400 | **0.5–2.0** | 0.02–0.25 |
| Microwave oven | 73–200 | **4–8** | 0.25–0.60 |
| Portable radio | 16–56 | **1** | <0.01 |
| Electric oven | 1–50 | **0.15–0.5** | 0.01–0.04 |
| Washing machine | 0.8–50 | **0.15–3.00** | 0.01–0.15 |
| Iron | 8–30 | **0.12–0.30** | 0.01–0.03 |
| Dishwasher | 3.5–20 | **0.6–3.0** | 0.07–0.3 |
| Computer | 0.5–30 | **<0.01** | NA |
| Refrigerator | 0.5–1.7 | **0.01–0.25** | <0.01 |
| Colour TV | 2.5–50 | 0.04–2.00 | **0.01–0.15** |

**Normal operating distance is given in bold.**
Abbreviations: T = tesla; NA = not applicable. All appliances operate at a frequency of 50 Hz; 1 μT = 10 mG
Source: WHO (2012a)

## Systematic literature review

*SQ5. IS THERE ANY RELIABLE EVIDENCE OF AN ASSOCIATION BETWEEN ELECTROMAGNETIC RADIATION FROM WIND TURBINES AND ADVERSE HEALTH EFFECTS?*

No studies were identified that considered the effect of 'electromagnetic radiation', as it relates to wind turbines, on human health. Given the lack of evidence to answer this question, an Evidence Statement Form was not completed and an evidence statement or conclusion was not able to be made.

## Parallel evidence

*BQ4. IS THERE BASIC BIOLOGICAL EVIDENCE, OR EVIDENCE FROM RESEARCH INTO OTHER CIRCUMSTANCES OF HUMAN EXPOSURE TO ELECTROMAGNETIC RADIATION, THAT MAKE IT PLAUSIBLE THAT WIND TURBINES CAUSE ADVERSE HEALTH EFFECTS?*

The parallel evidence identified for Background Question 4 concerning the effects of EMR in the ELF frequency range on human health is summarised in Table 38. This evidence was used to address the biological plausibility that wind farms could cause adverse health effects if they produced significant ELF. The specific limitations of each of the studies are also provided.

Three studies by Johansen and colleagues considered the potential health effects of EMR. Reported outcomes were diseases of the central nervous system (CNS), a range of cancers and the incidence of cardiac pacemaker implantation (Johansen 2000; Johansen, Feychting et al. 2002; Johansen & Olsen 1998). Slight increases for some diseases of the CNS (senile dementia, motor neuron diseases, amyotrophic lateral sclerosis (ALS)) were reported among exposed groups. However, the retrospective study design is likely to have resulted in exposure misclassification, while the exposed and non-exposed groups may have differed with respect to demographic factors and health and disease status. It is therefore uncertain whether the differences in CNS disease risk were due to ELF or to bias or confounding. A review by Ahlbom et al. (2001) considered the effects of environmental ELF on various cancers and ALS, noting an increase in the risk of childhood leukaemia and ALS for the exposed group, but the authors cautioned that the results are highly likely to have been affected by bias and confounding. One study reported a statistically significant effect of ELF on sleep (Åkerstedt et al. 1999), although the absolute impact was not considered meaningful.

According to the WHO (2012), the acceptable ELF health threshold is 100 µT (1000 mG). However, epidemiological studies of magnetic fields have consistently found an association between ELF at exposures of 0.4 µT or above and childhood leukaemia (Ahlbom et al. 2001), although lack of a known mechanism and negative animal data prevent a conclusion that the ELF and childhood leukaemia association is causal (Kheifets & Shimkhada 2005). Other authors make the more specific claim that prolonged exposure to power frequency ELF at levels above what is normally encountered (>4 mG or >0.4 µT) may be associated with an increased risk of childhood leukaemia (Karipidis & Martin 2005)[41]. These authors conducted a pilot study to characterise power-frequency ELF strength in private residences in metropolitan Melbourne, Victoria, Australia. The main objective was to gather results on the distribution of average ELF in homes and the proportion of homes with averages above 0.4 µT. The rationale was that this investigation provided data to inform a precautionary approach to EMF. The authors explained that such an

[41] The definition of 'levels above what is normally encountered' could not be clarified as the figure of >4 mG was based on a publication (ICNIRP 2003) not available to the authors at the time of undertaking this review. The quoted figure has been accepted as valid and 'levels normally encountered' has been interpreted to mean levels of EMF that people would commonly encounter during the course of their daily lives. For the same reason it could not be determined what is meant by 'prolonged exposure'.

approach necessitates ‘knowledge of the exposure potentially related to the possible risk’, meaning that ‘one should know what proportion of the population, and in particular children, are exposed to time-averaged levels above 4 mG’ (0.4 µT).

Table 35 shows magnetic field spot measurements and the percentage of homes for which each level was greater than 0.4 µT (95% CI). The results for the spot measurements did not, on average, exceed 0.4 µT despite isolated measurements above this figure. The authors acknowledge that the relevance of these findings is uncertain, the measurement not being representative of the population due to the small sample (Karipidis & Martin 2005).

Table 35 Magnetic field spot measurements at selected locations in 26 homes and percentage of homes (95%CI) for which the level exceeded 0.4 µT[a] at that location

| Location | No. of homes | Mean, µT | Median, µT | SD, µT | Min, µT | Max, µT | % homes >0.4 µT [95%CI] |
|---|---|---|---|---|---|---|---|
| Front gate | 25 | 0.334 | 0.200 | 0.319 | 0.02 | 1.16 | 28 [14, 48] |
| Front yard | 23 | 0.183 | 0.140 | 0.161 | 0.02 | 0.69 | 9 [1, 28] |
| Front door | 26 | 0.158 | 0.095 | 0.218 | 0.02 | 1.12 | 8 [1, 26] |
| Living room | 26 | 0.122 | 0.080 | 0.150 | 0.01 | 0.58 | 8 [1, 26] |
| Kitchen | 26 | 0.107 | 0.060 | 0.123 | 0.01 | 0.50 | 4 [0.1, 21] |
| Master bedroom | 26 | 0.139 | 0.075 | 0.194 | 0.01 | 0.92 | 12 [3, 30] |
| Child’s bedroom | 26 | 0.151 | 0.080 | 0.212 | 0.01 | 0.99 | 12 [3, 30] |
| Study | | 0.147 | 0.070 | 0.197 | 0.01 | 0.59 | 14 [3, 42] |
| Backyard | | 0.097 | 0.050 | 0.140 | 0.01 | 0.68 | 4 [0.1, 21] |

Abbreviations: µT = microtesla; SD = standard deviation; CI = confidence interval
[a] All results have been converted from milligauss to microtesla.
Source: Karipidis and Martin (2005)

Magnetic fields from appliances usually showed considerable variation from house to house for the same types of appliance. Fields produced by microwave ovens were observed to have the highest levels. Table 36 shows descriptive statistics for selected appliances.

Table 36 Descriptive statistics for magnetic fields from selected appliances measured at a nominal 30-cm separation[a]

| Appliance | No. of homes | Mean, µT | Median, µT | SD, µT | Min, µT | Max, µT |
|---|---|---|---|---|---|---|
| Television | 26 | 1.01 | 0.99 | 0.57 | 0.14 | 2.54 |
| Microwave oven | 22 | 9.71 | 10.60 | 5.45 | 0.77 | 18.80 |
| Kettle | 22 | 0.53 | 0.47 | 0.32 | 0.17 | 1.38 |
| Clock radio | 22 | 0.48 | 0.45 | 0.25 | 0.14 | 0.96 |
| Hair dryer | 9 | 2.53 | 0.95 | 3.18 | 0.26 | 9.90 |
| Computer | 17 | 0.23 | 0.23 | 0.12 | 0.06 | 0.52 |

Abbreviations: µT = microtesla; SD = standard deviation
[a] All results have been converted from milligauss to microtesla.
Source: Karipidis and Martin (2005)

These results suggest that the magnetic fields associated with common household appliances do not reach average levels exceeding 0.4 µT, and that the levels of ELF experienced by individuals on a day-to-day basis around the home may occasionally fall within ranges consistent with an elevated risk of childhood leukaemia where the exposure is close and prolonged[42] (ICNIRP 2003). However, it is uncertain how many of, or for how long, these sources would regularly be within 30 cm (the nominal separation) of residents for extended periods.

A WHO report on EMF and health concluded that magnetic field strength rapidly decreases as distance from the appliance increases (WHO 2012b). The WHO noted that, for the majority of household appliances that are not operated in very close proximity to the body (i.e. >30 cm), the magnetic fields surrounding these appliances are substantially lower than the WHO guideline limit of 100 µT at 50 Hz (83 µT at 60 Hz) for the general public. Thus, if human exposure to ELF from wind turbines is considered to be of similar strength to that emitted by household appliances, these conclusions would have similar applicability. As noted above, there is some evidence to suggest that the levels of ELF measured around turbines are less than those measured close to household appliances and in a number of working and home environments. These measurements were taken at proximities from the turbines that would be much closer than that of residences near turbines (Windrush Energy 2004). However, the measurements were only summarised (no datasets) and were taken by a party within the wind power industry. Comprehensive measurements and data reporting across a range of wind farms have not been provided by an independent investigator.

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[42] As the International Committee Report could not be accessed, the definition of prolonged is unknown; however, one example of prolonged exposure within close range was given by Karipidis and Martin (2005)—a clock radio on a bedside table.

Another pilot study (Kim & Cho 2001) conducted in Korea compared personal exposure to ELF among 'occupational' and 'non-occupational' groups[43] in different indoor environments (at work, transportation and at home) and outdoors. The results of magnetic field strength measurements taken in the various environments for these groups are shown in Table 37.

Table 37 Average levels of personal exposure (µT) to magnetic fields in occupational and non-occupational groups

| | Occupational group (O) | | | | Non-occupational group (NO) | | Ratio |
|---|---|---|---|---|---|---|---|
| | **Electrician (n=11)** | **Medical computer operator (n=6)** | **Subway driver (n=9)** | **Transformer worker (n=11)** | **Graduate student (n=34)** | **Office worker (n=31)** | **O/NO** |
| Indoor, µT: | | | | | | | |
| at work | 0.64 | 0.46 | 0.35 | 1.21 | 0.09 | 0.09 | 7.44 |
| in transport | 0.42 | 0.18 | 0.26 | 0.22 | 0.22 | 0.13 | 1.50 |
| at home | 0.18 | 0.18 | 0.08 | 0.08 | 0.07 | 0.07 | 1.86 |
| etc.[a] | 0.13 | 0.11 | 0.18 | 0.33 | 0.13 | 0.06 | 1.90 |
| Outdoor, µT | 0.26 | 0.08 | 0.15 | 0.11 | 0.17 | 0.09 | 1.15 |
| Total, µT | 0.41 | 0.27 | 0.18 | 0.83 | 0.08 | 0.08 | 5.25 |

Abbreviations: µT = microtesla; O/NO = occupational/non-occupational
[a] It is unclear from the publication which indoor environments provided the measurements shown in this row.
Source: Kim and Cho (2001)

The study groups without probable occupational exposure to ELF had average workplace levels of exposure that were similar to the home levels—0.09 µT compared with 0.07 µT. In contrast, those with occupational exposure had much higher levels of workplace exposure (0.35–1.21 µT) than home exposure (0.08–0.18 µT).

The former findings are generally consistent with those of an investigation that measured ELF exposure in 10 women working at a television studio in Toowong, Queensland, Australia (Armstrong et al. 2007). The investigation was in response to a breast cancer cluster observed among the 10 women who were studied. The average levels measured at Toowong, with the exception of measurements for a staff member who worked in the radio building, were similar to those in the Korean study without probable occupational exposure. Levels measured from the radio building were appreciably less than that measured on any of the Korean groups with probable occupational exposure.

[43] While the publication by Kim and Cho (2001) did not provide explicit definitions for these groups, it is evident that 'occupational' was intended to encompass occupations hypothesised to be associated with higher levels of ELF exposure than 'non-occupational', which included graduate students and office workers.

Overall, the findings of the Toowong study suggest that ELF was a very unlikely cause for the observed breast cancer cluster, as the levels of exposure were very unlikely to have been materially different from levels common in residential buildings, and probably workplaces, in Australia.

Given that the only available estimates of ELF levels in proximity to wind farms (Windrush Energy 2004) are lower than the levels observed in this evidence, it would be reasonable to conclude that the likelihood of adverse health effects from ELF emitted by wind turbines is probably very low, albeit currently unknown.

Several of the ELF studies shown in Table 38 used a job-exposure matrix. This has the potential to result in misclassification between adjacent categories of exposure (Johansen et al. 2002). Three key limitations with respect to ELF exposure assessment discussed in the literature include the lack of knowledge about a relevant metric and the relevant exposure induction period; the retrospective nature of exposure assessment in the majority of the studies; and incomplete characterisation of exposure sources, and lack of consensus on combining exposures from different sources into one metric (Ahlbom et al. 2001).

The cyclical nature of exposures from power lines makes the nature of the exposure complex, multifaceted and highly variable (daily, seasonal and secular patterns; variation in residential exposure due to differences in power usage (intensity and duration) across both time and electrical appliances). There are also two additional key issues for consideration: 1) the magnetic field exposure from sources outside those examined in the studies, such as magnetic fields outside the home; and 2) residential mobility.

It is difficult to precisely determine if there exists an aetiologic relationship between ELF exposure and chronic disease endpoints such as cancer in the absence of prospective attainment of accurate data. However, among the evaluated studies, the strongest evidence of an association was in relation to postnatal exposures to ELF above 0.4 μT and childhood leukaemia, based on two separate non-systematic reviews presenting pooled analyses (Ahlbom et al. 2001; Kheifets & Shimkhada 2005).

While there are numerous studies of childhood leukaemia and ELF exposure, studies of ELF exposure and other diseases (particularly adult diseases) are much more limited. This is largely due to difficulties typically encountered in designing studies that adequately assess exposure (Kheifets & Shimkhada 2005). Outside the study of childhood leukaemia, results from the ELF studies are characterised by a high degree of heterogeneity and are inconclusive. The applicability of the results obtained in the included ELF studies to the wind farms context is uncertain due to scant data (one industry example only (Windrush Energy 2004)) on the magnitude and/or level (quantity) of ELF present in the vicinity of wind turbines.

Table 38 Parallel evidence examining the association between extremely low frequency electromagnetic fields (ELF) and adverse health effects

| Study | Design | Exposure | Outcomes | Limitations |
|---|---|---|---|---|
| Åkerstedt et al. (1999) | Cross-over design comparing sleep with and without exposure to a 50 Hz/1 µT electrical field.<br>n=18 healthy subjects (age range 18–50 years). | After a night of habituation, subjects were exposed 3–5 days later to a night with a 1 µT EMF field on or off. Magnetic fields measured using a 3-axis magnetometer.<br>The authors note that the generated field did not cause any sound. | Effects on sleep (polysomnography. Effects on sleep-related hormones (melatonin, growth hormones, cortisol and prolactin). | Authors stated that, despite statistically significant differences, effects were far from 'clinical significance'. |

**Results**

*Mean values for sleep variables with ELF 'Off' and 'On'*

| | On, mean±SE | Off, mean±SE | p value |
|---|---|---|---|
| Total sleep time | 424±9 | 407±11 | 0.04 |
| Sleep efficiency | 0.86±0.02 | 0.82±0.02 | 0.05 |
| Awakenings | 1.34±0.03 | 2.41±0.04 | 0.07 |
| Sleep latency | 18±4 | 22±6 | 0.29 |
| SWS latency | 12±1 | 14±2 | 0.20 |
| REM sleep latency | 81±9 | 80±9 | 0.44 |
| Stage 1 sleep | 8±2 | 10±1 | 0.16 |
| Stage 2 sleep | 219±10 | 211±10 | 0.10 |
| SWS | 97±4 | 82±6 | 0.01 |
| SWA% | 100 | 80±9 | 0.02 |

| Study | Design | Exposure | Outcomes | Limitations |
|---|---|---|---|---|
| REM | 107±7 | 104±6 | 0.34 | |
| Stage wake + movement | 45±9 | 54±8 | 0.10 | |
| Subject rated[a] | | | | |
| Ease of falling asleep | 4.1±0.2 | 4.2±0.2 | 0.15 | |
| Ease of awakening | 3.6±0.2 | 3.8±0.2 | 0.12 | |
| Sleep quality | 3.7±0.2 | 4.0±0.2 | 0.09 | |
| Sleep depth | 3.9±0.2 | 3.4±0.2 | 0.01 | |
| Undisturbed sleep | 3.2±0.2 | 3.3±0.2 | 0.20 | |

All values given in minutes except for sleep efficiency (proportion), SWA (%) and subjective ratings (point scale; see [a] below).

[a] The Karolinska Sleep Diary was used. Items were scored 1 to 5, where '5' indicated highest quality or greatest ease.

SWS, SWA, REM, see Abbreviations list at end of this table.

*Mean and ANOVA results for plasma hormone levels at five time points with ELF 'Off' and 'On'*

| | 23.00 | 24.00 | 2.30 | 5.00 | 8.00 | $F^{time}$ | $F^{condition}$ | $F^{tc}$ |
|---|---|---|---|---|---|---|---|---|
| Melatonin, Off | 34±8 | 53±8 | 110±11 | 60±11 | 28±7 | NA | NA | NA |
| Melatonin, On | 25±7 | 36±7 | 67±8 | 55±8 | 35±7 | 5.7[a] | 1.5 | 0.8[a] |
| GH, Off | 1.6±0.9 | 1.3±0.4 | 2.0±0.1 | 0.6±0.1 | 0.3±0.1 | NA | NA | NA |
| GH, On | 1.5±0.6 | 2.5±0.6 | 1.2±0.1 | 0.6±0.1 | 0.3±0.1 | 6.0[b] | 0.6 | 1.6[a] |
| Cortisol, Off | 105±15 | 102±24 | 70±20 | 184±20 | 357±20 | NA | NA | NA |
| Cortisol, On | 103±11 | 114±24 | 108±24 | 209±24 | 365±18 | 63.1[c] | 3.2 | 0.5[a] |
| ACTH, Off | 1.8±0.4 | 1.3±0.1 | 1.7±0.3 | 3.1±0.5 | 5.5±2.5 | NA | NA | NA |
| ACTH, On | 1.6±0.3 | 1.8±0.7 | 1.2±0.1 | 3.0±0.4 | 4.2±0.3 | 22.9[c] | 3.6 | 2.2[a] |
| Prolactin, Off | 5.6±0.5 | 5.9±1.1 | 9.6±1.2 | 9.0±0.9 | 12±1.5 | NA | NA | NA |
| Prolactin, On | 5.9±0.7 | 4.6±0.4 | 9.3±0.7 | 7.6±0.7 | 11±1.2 | 19.9[c] | 1.3 | 0.4[a] |

<table>
<tr><th>Study</th><th>Design</th><th>Exposure</th><th>Outcomes</th><th>Limitations</th></tr>
<tr><td colspan="5">$F^{time}$ = adjusted statistic derived from testing for changes across the night with 'time' as a factor; $F^{condition}$ = adjusted statistic derived from testing for changes across the night with 'condition'(off/on) as a factor; $F^{tc}$ = adjusted statistic derived from testing for changes across the night with 'time' and 'condition' as factors.<br>p values: [a] <0.05; [b] <0.01; [c] <0.001.<br>Melatonin and ACTH (see Abbreviations list at end of this table) levels given in pmol/L, cortisol in nmol/L, GH (see Abbreviations) and prolactin in µg/L (see Glossary for definitions of these units).<br>Summary<br>ELF exposure was associated with reduced: total sleep time, sleep efficiency and slow wave activity (SWA). There were no differences in plasma hormone levels between exposed and non-exposed phases.</td></tr>
<tr><td>Johansen (2000)†</td><td>Retrospective cohort study to examine whether there was any association between ELF and diseases of the CNS in approximately 31,000 subjects employed in Danish utility companies between 1900 and 1993. After classification of exposure, data were linked to the nationwide, population-based Danish national register of patients to determine the number of CNS disease cases.</td><td>A job-exposure matrix specific for ELF (that distinguished between 25 job titles held by workers in utility companies) was constructed and, for each of the 475 combinations of job title and work area, an average level of exposure of 50 Hz ELF during a working day was assigned.<br>This was grouped into five categories of ELF exposure: background exposure (0.09 µT), low exposure (0.1–0.29 µT), medium exposure (0.3– 0.99 µT), and high exposure (>1.0 µT).</td><td>Diseases of the CNS—dementia, demyelinating diseases, cerebral palsy, epilepsy, motor neuron diseases and spinal medullary disease.</td><td>Limitations include retrospective design of the study, potential for misclassification of exposure and non-randomised nature of the comparison.</td></tr>
<tr><td colspan="5">Results</td></tr>
</table>

| Study | Design | Exposure | Outcomes | Limitations |
|---|---|---|---|---|

*Observed (O) and expected (E) discharges (1978–1993) due to CNS diseases among 30,631 workers with ≥3 months employment at a utility company in Denmark during 1900–1993*

| | Men | | | | Women | | | |
|---|---|---|---|---|---|---|---|---|
| | O | E | O/E | 95% CI | O | E | O/E | 95% CI |
| Disease (ICD-8) | | | | | | | | |
| Senile dementia | 122 | 105.1 | 1.16 | [0.16,1.39] | 6 | 11.95 | 0.50 | [0.18,1.03] |
| Presenility | 30 | 33.5 | 0.90 | [0.60,1.28] | 4 | 2.99 | 1.34 | [0.36,3.43] |
| Demyelinating diseases in CNS | 4 | 2.11 | 1.90 | [0.51,4.86] | 1 | 0.54 | 1.86 | [0.02,10.32] |
| Parkinson's disease | 64 | 71.5 | 0.90 | [0.69,1.14] | 4 | 6.40 | 0.62 | [0.17,1.60] |
| Cerebral palsy | 45 | 52.5 | 0.86 | [0.62,1.15] | 8 | 5.16 | 1.55 | [0.67,3.06] |
| Epilepsy | 148 | 196.2 | 0.75 | [0.64,0.89] | 19 | 31.68 | 0.60 | [0.36,0.94] |
| Motor neuron diseases (non-ALS) | 5 | 1.82 | 2.75 | [0.88,6.41] | 0 | 0.22 | 0 | [0.00,16.80] |
| ALS | 15 | 8.7 | 1.72 | [0.96,2.83] | 0 | 0.82 | 0 | [0.00,4.50] |
| Spinal medullary disease | 13 | 21.29 | 0.61 | [0.32,1.04] | 3 | 2.65 | 1.13 | [0.23,3.31] |

*Relative risk of neurological diseases among 24,850 men employed in Danish utility companies by average estimated level of EMF exposure, adjusted for age, calendar period and duration of employment*

| | Background (<0.09 μT) | | Low (0.10–0.29 μT) | | Medium (0.30–0.99 μT) | | High (≥1.0 μT) | | Unknown | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | RR | RR | 95% CI | RR | 95% CI | RR | 95% CI | RR | 95% CI |
| Disease (ICD-8) | | | | | | | | | | |
| Senile dementia | 122 | 1.00 | 1.00 | [0.51,1.95] | 1.15 | [0.60,2.19] | 1.43 | [0.74,2.77] | 1.51 | [0.78,2.94] |
| Presenility | 30 | 1.00 | 0.68 | [0.20,2.34] | 0.72 | [0.21,2.48] | 0.92 | [0.25,3.42] | 1.21 | [0.34,4.32] |
| Parkinson disease | 64 | 1.00 | 0.89 | [0.42,1.87] | 0.68 | [0.31,1.49] | 0.64 | [0.26,1.54] | 0.72 | [0.29,1.79] |

| Study | Design | Exposure | Outcomes | Limitations |
|---|---|---|---|---|

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cerebral palsy | 45 | 1.00 | 0.50 | [0.16,1.54] | 0.88 | [0.33,2.39] | 0.78 | [0.25,2.42] | 2.57 | [0.92,7.19] |
| Epilepsy | 148 | 1.00 | 1.51 | [0.78,2.95] | 1.50 | [0.77,2.94] | 2.03 | [1.02,4.05] | 1.61 | [0.79,3.29] |
| Motor neuron disease | 20 | 1.00 | 0.86 | [0.16,4.71] | 1.27 | [0.26,6.32] | 1.56 | [0.29,8.53] | 1.90 | [0.33,11.13] |
| Spinal medullary disease | 13 | 1.00 | 1.35 | [0.14,13.04] | 1.35 | [0.14,12.97] | 0.81 | [0.05,12.96] | 3.96 | [0.43,36.59] |

**Summary**

Overall, there was an increased risk of senile dementia and motor neuron diseases (although differences were not statistically significant). The authors speculated that this may be associated with 'above-average' levels of exposure to magnetic fields. The incidences of Parkinson's disease, Alzheimer's disease, and other diseases of the CNS were not associated with exposure to ELF. The authors note that there was a decreased risk of epilepsy compared with the general population, which was likely related to a healthy worker effect.

| Study | Design | Exposure | Outcomes | Limitations |
|---|---|---|---|---|
| Johansen, Feychting et al. (2002)† | Retrospective cohort study. Investigators attempted to examine concerns about potential cardiovascular effects of occupational exposure to ELF.<br>A cohort of approximately 24,000 men who worked in utility companies in Denmark (between 1900 and 1993) was linked to the nationwide, population-based Danish Pacemaker Register, and the numbers of persons who had undergone pacemaker implantation between 1982 and 2000 were compared with corresponding numbers in the general population. | Exposure to ELF in the 50–60 Hz frequency band.<br>For each of the 475 combinations of job titles/work areas, an average level of exposure to 50 Hz ELF during a working day was assigned.<br>These were also categorised into ELF (background exposure (≤0.09 µT), medium exposure (0.1–0.99 µT), and high exposure (≥1.0 µT)). | Incidence ratios for pacemaker implantation. | Awareness of exposure and observer bias in level or intensity of determining the outcome from registers.<br>The study addresses only those heart diseases that require implantation of a pacemaker.<br>Assessment of exposure was not obtained from individual data.<br>No information about other exposures or lifestyle factors associated with cardiovascular disease (cigarette smoking, diet or physical activity) was collected, so the possibility of confounding cannot be excluded. |

| Study | Design | Exposure | Outcomes | Limitations |
|---|---|---|---|---|

**Results**

*Standardised incidence ratios for pacemaker implantation during the period 1982–2000 among 24,056 men employed ≥3 months at a utility company in Denmark during 1900–1993, by average estimated level of exposure to electromagnetic fields at work and duration of employment*

| | Background exposure (≤0.09 µT; n=20) | | Medium exposure (0.1–0.99 µT; n=61) | | High exposure (>1.0 µT; n=23) | | Unknown (n=31) | |
|---|---|---|---|---|---|---|---|---|
| | Obs/Expt | SIR [95% CI] | Obs/Expt | SIR [95% CI] | Obs/Expt | SIR [95% CI] | Obs/Expt | SIR [95% CI] |
| Employment duration, years | | | | | | | | |
| 0–9 | -/0.65 | - | 3/2.64 | 1.14 [0.2,3.3] | -/0.86 | - | 2/0.77 | 2.60 [0.3,9.4] |
| 10–19 | -/2.59 | - | 14/9.91 | 1.41 [0.8,2.4] | 3/3.32 | 0.90 [0.2,2.6] | 7/4.38 | 1.60 [0.6,3.3] |
| ≥20 | 20/14.86 | 1.35 [0.8,2.1] | 44/60.97 | 0.72 [0.5,1.0] | 20/18.86 | 1.06 [0.7,1.6] | 22/20.41 | 1.08 [0.7,1.6] |
| Total | 20/18.10 | 1.11 [0.7,1.7] | 61/73.51 | 0.83 [0.6,1.1] | 23/23.04 | 1.00 [0.6,1.5] | 31/25.55 | 1.21 [0.8,1.7] |

*Relative risk of pacemaker implantation among 24,056 men employed ≥3 months at a utility company in Denmark during 1990–1993, by average estimated level of ELF exposure at work[a], adjusted for age calendar year and duration of employment*

| Background exposure (≤0.09 µT; n=20) | Medium exposure (0.1–0.99 µT; n=61) | High exposure (>1.0 µT; n=23) | Unknown (n=31) |
|---|---|---|---|
| RR | RR [95% CI] | RR [95% CI] | RR [95% CI] |
| 1.0[b] | 1.6 [0.6,1.87] | 0.89 [0.5,1.63] | 1.06 [0.61,1.87] |

[a] p for trend = 0.7; [b] Reference category

**Summary**

Overall, there was no statistically significant increased frequency of pacemaker implantation among employees: 135 subjects received implants, yielding a risk estimate of 0.96 (95% CI [0.81, 1.14]). No clear dose–response pattern emerged with increasing ELF exposure or with duration of employment. A Poisson regression analysis was conducted, which showed no statistically significant increased risk in the group with high exposure compared with the group with background exposure, and there was no observed trend in the risk estimate when workers were compared according to their level of occupational exposure to

| Study | Design | Exposure | Outcomes | Limitations |
|---|---|---|---|---|
| electromagnetic fields (p=0.7). | | | | |
| Johansen and Olsen (1998)† | Johansen and Olsen conducted 8 separate cohort studies among Danish utility workers to examine any increased risk of cancer, ALS, multiple sclerosis, CNS diseases and other chronic disorders, as well as cause-specific mortality associated with ELF.<br>All employees were followed up in several registers. Risk of disease was analysed in relation to occupational ELF exposure, latency, and duration of employment. A specific job-exposure matrix was developed and validated by comparison with direct measurements of ELF during a workday. | Disease among employees exposed to ELF (50-Hz) in the Danish utility industry. | Any increased risk of cancer, ALS, multiple sclerosis, CNS diseases and other chronic disorders, and cause-specific mortality. | |

**Results**

*Observed numbers of deaths and standardised mortality ratios by selected causes of death and time since first employment among 21,236 men with ≥3 months employment at a utility company in Denmark during 1900–1993*

| | | | Time since first employment | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 0–9 years | | 10–29 years | | >30 years | |
| | Observed | SMR | Observed | SMR | Observed | SMR | Observed | SMR |
| Cause of death | | | | | | | | |
| All causes | 3540 | 0.96 | 305 | 0.82 | 1869 | 0.97 | 1366 | 0.98 |
| All malignant neoplasms | 1070 | 1.1[a] | 71 | 0.8 | 576 | 1.1 | 423 | 1.1[a] |

| Study | Design | | Exposure | | Outcomes | | Limitations | |
|---|---|---|---|---|---|---|---|---|
| Leukaemia | 30 | 0.9 | 3 | 0.7 | 13 | 0.8 | 14 | 1.2 |
| Breast cancer | 2 | 1.6 | 0 | 0 | 1 | 1.5 | 1 | 2.2 |
| Brain cancer | 4 | 1.4 | 1 | 1.7 | 0 | 0 | 3 | 4.5 |
| Lung cancer | 343 | 1.1[a] | 22 | 0.9 | 199 | 1.2[a] | 122 | 1.1 |
| Pleural cancer | 14 | 2.3[a] | 0 | 0 | 8 | 2.3 | 6 | 2.9[a] |
| Neurological disorders | | | | | | | | |
| ALS | 14 | 2.0[a] | 0 | 0 | 8 | 2.0 | 6 | 2.7[a] |
| Parkinson's disease | 6 | 0.8 | 0 | 0 | 3 | 0.8 | 3 | 0.8 |
| Multiple sclerosis | 3 | 0.4 | 0 | 0 | 2 | 0.5 | 1 | 0.7 |
| Senile dementia | 4 | 0.5 | 0 | 0 | 3 | 1.0 | 1 | 0.2 |
| Presenile dementia | 2 | 0.9 | 0 | 0 | 1 | 0.8 | 1 | 1.0 |
| Behaviour-related causes | | | | | | | | |
| Accidents caused by | | | | | | | | |
| Electricity | 10 | 18.1[a] | 2 | 8.0 | 8 | 29.2[a] | 0 | 0 |
| Alcoholism | 21 | 1.0 | 8 | 2.2 | 12 | 0.9 | 1 | 0.3 |
| Motor vehicles | 49 | 0.9 | 19 | 1.0 | 22 | 0.9 | 8 | 0.9 |
| Suicide | 133 | 0.9 | 36 | 0.9 | 82 | 1.0 | 15 | 0.8 |
| Cardiovascular disorders | | | | | | | | |
| Acute myocardial infarction | 713 | 1.0 | 54 | 0.9 | 385 | 1.0 | 274 | 1.0 |
| Cardiac arteriosclerosis | 300 | 0.9 | 12 | 0.8 | 151 | 1.0 | 137 | 0.9 |
| Other heart diseases | 152 | 0.9 | 9 | 0.7 | 78 | 0.9 | 65 | 0.9 |
| Cerebrovascular disease | 207 | 0.8 | 14 | 1.0 | 101 | 0.8 | 92 | 0.8 |
| Respiratory disorders | | | | | | | | |
| Bronchitis and emphysema | 159 | 1.0 | 7 | 0.9 | 87 | 1.1 | 65 | 1.0 |

| Study | Design | | Exposure | | Outcomes | | Limitations | |
|---|---|---|---|---|---|---|---|---|
| Asthma | 4 | 0.4 | 0 | 0 | 3 | 0.5 | 1 | 0.3 |
| Other specified causes | 644 | 0.9 | 67 | 0.7 | 329 | 0.9 | 248 | 1.0 |
| Unknown cause | 49 | 0.9 | 4 | 0.7 | 18 | 0.9 | 25 | 1.0 |

[a] p<0.05

*Observed numbers of deaths and standardised mortality ratios by selected causes of death and estimated average workplace exposure to 50 Hz magnetic fields among 21,236 men with ≥3 months employment at a utility company in Denmark during 1900–1993*

| | Background exposure (≤0.09 µT) | | Low exposure (0.10–0.29 µT) | | Medium exposure (0.30–0.99 µT) | | High exposure (>1.0 µT) | |
|---|---|---|---|---|---|---|---|---|
| | Observed | SMR | Observed | SMR | Observed | SMR | Observed | SMR |
| Cause of death | | | | | | | | |
| All causes | 474 | 0.79 | 1063 | 0.93 | 1134 | 0.96 | 869 | 1.12[a] |
| All malignant neoplasms | 151 | 0.9 | 301 | 1.0 | 366 | 1.2[a] | 252 | 1.2[a] |
| Leukaemia | 2 | 0.4 | 7 | 0.7 | 15 | 1.4 | 6 | 0.9 |
| Breast cancer | 0 | 0 | 1 | 2.6 | 0 | 0 | 1 | 4.0 |
| Brain cancer | 0 | 0 | 2 | 2.1 | 2 | 2.1 | 0 | 0 |
| Lung cancer | 47 | 1.0 | 88 | 1.0 | 117 | 1.2[a] | 91 | 1.4[a] |
| Pleural cancer | 0 | 0 | 2 | 1.0 | 7 | 3.5[a] | 5 | 4.0[a] |
| Neurological disorders | | | | | | | | |
| ALS | 1 | 0.9 | 4 | 1.9 | 5 | 2.3 | 4 | 2.8 |
| Parkinson's disease | 1 | 0.7 | 3 | 1.3 | 1 | 0.4 | 1 | 0.6 |
| Multiple sclerosis | 0 | 0 | 0 | 0 | 2 | 0.9 | 1 | 0.8 |
| Senile dementia | 0 | 0 | 1 | 0.4 | 2 | 0.8 | 1 | 0.6 |
| Presenile dementia | 0 | 0 | 1 | 1.4 | 1 | 1.3 | 0 | 0 |
| Behaviour-related causes | | | | | | | | |

| Study | Design | | | Exposure | | Outcomes | | Limitations |
|---|---|---|---|---|---|---|---|---|
| Accidents caused by Electricity | 0 | 0 | 2 | 10.1[a] | 5 | 26.9[a] | 3 | 30.8[a] |
| Alcoholism | 1 | 0.4 | 10 | 1.5 | 6 | 0.9 | 3 | 1.1 |
| Motor vehicles | 4 | 0.5 | 24 | 1.3 | 12 | 0.7 | 9 | 0.9 |
| Suicide | 19 | 1.0 | 37 | 0.8 | 41 | 0.9 | 36 | 1.4 |
| Cardiovascular disorders | | | | | | | | |
| Acute myocardial infarction | 96 | 0.8 | 225 | 1.0 | 232 | 1.0 | 160 | 1.0 |
| Cardiac arteriosclerosis | 38 | 0.7 | 98 | 1.0 | 79 | 0.8 | 85 | 1.2 |
| Other heart diseases | 27 | 0.9 | 35 | 0.7 | 52 | 1.0 | 38 | 1.1 |
| Cerebrovascular disease | 24 | 0.6 | 68 | 0.9 | 61 | 0.8 | 54 | 1.0 |
| Respiratory disorders | | | | | | | | |
| Bronchitis and emphysema | 20 | 0.8 | 50 | 1.1 | 48 | 1.0 | 41 | 1.2 |
| Asthma | 2 | 1.1 | 1 | 0.3 | 1 | 0.3 | 0 | 0 |
| Other specified causes | 82 | 0.7 | 189 | 0.8 | 203 | 0.9 | 170 | 1.1 |
| Unknown cause | 8 | 0.9 | 14 | 0.8 | 17 | 0.9 | 10 | 0.9 |

[a] $p<0.05$

**Summary**

Linkage with the Danish Cancer Register did not identify increased risks for those cancers suggested *a priori* to be associated with exposure to ELF, including leukaemia, brain tumours and breast cancer. Linkage with the National Mortality Register revealed a significantly increased overall mortality rate from ALS, with an increasing trend with duration of employment and ELF exposure. In addition, a significantly increased mortality rate from electric accidents was observed. It was hypothesised that the observation of increased mortality from ALS was associated with exposure to ELF or electric shocks. No increased mortality rate from cardiovascular or cerebrovascular disease was observed. Linkage of the cohort with the Multiple Sclerosis Register revealed an increased risk of multiple sclerosis, which was not, however, significant. Linkage with the Pacemaker Register showed no increased risk of severe arrhythmia-related heart disease.

| Study | Design | Exposure | Outcomes | Limitations |
|---|---|---|---|---|
| Ahlbom et al. (2001) | Comprehensive non-systematic review.<br>18 studies included on ELF and childhood cancer—17 case-control studies (2 nested) and one cohort study.<br>7 studies included on ELF and amyotrophic lateral sclerosis (ALS)—5 case-control and 2 cohort studies.<br>5 studies included on ELF and Alzheimer's disease—4 case-control studies and one cohort study.<br>5 studies on ELF and suicide—2 case-controls and 3 studies calculated the standardised or proportional mortality ratio.<br>6 studies on ELF and depression—5 cross-sectional and one case-control study.<br>Authors presented a narrative discussion of studies on the association between occupational/residential exposures to ELF and either cardiovascular risk or reproductive adverse effects, but did not specify the number of studies. | ELF from a range of sources including residential (close proximity to power lines) and occupational (e.g. video display terminals) ELF exposures.<br>Authors considered ELF as time-varying electric and/or magnetic fields <300 Hz; however, most included studies, where specified, assessed magnetic fields <60 Hz. | Various cancers and ALS. | The authors caution that the observed associations from reviewed studies are highly uncertain due to potential for bias and confounding. There was uncertainty regarding the methods used to measure and categorise ELF, leading to potential misclassification and difficulty in comparing/combining studies. |
| **Results**<br>*Pooled analysis of studies (n=9) on ELF exposure and childhood leukaemia* | | | | |

| Study | Design | Exposure | Outcomes | Limitations |
|---|---|---|---|---|

| | Summary residential ELF exposure <0.4 µT | Estimated residential ELF exposure ≥0.4 µT |
|---|---|---|
| Cases, n | | |
| Observed | 3,203 | 44 |
| Expected | NR | 24.2 |
| Excess | NR | 19.8 |
| Controls, n | 10,338 | 62 |
| RR [95% CI] | NR[a] | 2.0 [1.27,3.13] |

[a] While no data were provided, the authors reported that the risk was found 'to be near the no-effect level'.

*Pooled analysis of studies (n=14) on ELF exposure and ALS*

| Pooled studies | No. of studies | RR [95% CI] |
|---|---|---|
| All | 7 | 1.5 [1.2,1.7] |
| Clinically and ALS society-based | 3 | 3.3 [1.7,6.7] |
| Mortality registry and census-based | 2 | 1.3 [1.1,1.6] |
| Utility cohort studies | 2 | 2.7 [1.4,5.0] |

**Summary**

Among the evaluated outcomes, the one for which there was most evidence of an association was childhood leukaemia in relation to postnatal exposures above 0.4 µT. The relative risk was 2.0 (95% CI [1.27, 3.13]) from a large pooled analysis. There was some evidence of an association between ALS with occupational ELF exposure.

Abbreviations: RCT = randomised controlled trial; µT = microtesla; ELF = extremely low-frequency electromagnetic field(s); CNS = central nervous system; mT = millitesla; ELF = extremely low frequency electromagnetic field(s); ALS = amyotrophic lateral sclerosis; SWS = slow wave sleep; SWA = slow wave activity; REM = rapid eye movement; ANOVA = analysis of variance; ACTH = adrenocorticotropic hormone; GH = growth hormone; ICD-8 = International Classification of Diseases = Revision 8; RR = relative risk; CI = confidence interval; SMR = standardised mortality ratio; SIR = standardised incidence ratio; NR = not reported; SE = standard error; dB = decibels; NS = not (statistically) significant
† The Johansen ELF studies are based on the same cohort, with individual publications reporting different outcomes or sets of outcomes.

## SUMMARY: DIRECT, MECHANISTIC AND PARALLEL EVIDENCE ON EMR

*SQ5. Is there any reliable evidence of an association between electromagnetic radiation from wind turbines and adverse health effects?*

No studies were identified that considered the effect of 'electromagnetic radiation', as it relates to wind turbines, on human health.

*BQ2. By what specific physical emissions might wind turbines cause adverse health effects? (EMR)*

Mechanistic studies indicate that the effects of external exposure to EMR on the human body and its cells depend mainly on the EMR frequency and strength (WHO 2002). It is known that the strength of an alternating magnetic field rapidly decreases as distance from the source increases (WHO 2012b). ELF EMR can produce eddy currents in human tissue. Since biochemical mechanisms and nerve transmission utilise electric impulses, exposure to ELF EMR could interfere with electrical currents that are vital to normal bodily function if the person is in close proximity to the source of the EMR.

*BQ3. For each such emission, what is the level of exposure from a wind turbine and how does it vary by distance and characteristics of the terrain separating a wind turbine from potentially exposed people?*

In wind farms EMR is emitted from grid connection lines, underground collector network cabling, electrical transformers and turbine generators. However, there are scant data (one industry example only (Windrush Energy 2004)) on the magnitude and/or level (quantity) of ELF EMR present in the vicinity of wind turbines. The available industry data suggests that the ELF EMR levels near wind farms are likely to be within the range of ELF EMR emitted by household appliances.

**SUMMARY (CONT.)**

*BQ4. Is there basic biological evidence, or evidence from research into other circumstances of human exposure to electromagnetic radiation, that make it plausible that wind turbines cause adverse health effects?*

The applicability of the available parallel evidence on EMR to the wind farm context is uncertain. Concerns regarding the safety of EMR were raised with the publication of an early study reporting an association between the risk of childhood leukaemia and the degree of EMR exposure from electricity transmission lines (Wertheimer & Leeper 1979). Research has also been conducted on possible associations between occupational EMR and cancer or cardiovascular, neurological/psychological and reproductive diseases. However, apart from the study of childhood leukaemia, results from these EMR studies are characterised by a high degree of heterogeneity and are all considered to be inconclusive with respect to a causal association between EMR exposure and human health effects (Ahlbom et al. 2001).

# WIND TURBINE EXPOSURE AND HUMAN HEALTH EFFECTS ASSESSED AGAINST MODIFIED BRADFORD HILL CAUSALITY GUIDELINES

The direct, mechanistic and parallel evidence collated for this review was considered within the causality framework offered by the modified Bradford Hill Guidelines. Pre-specified indicators were used to determine whether there is a probable cause-and-effect relationship between exposure to wind turbine emissions and adverse health effects. Causation could not be demonstrated (Table 39).

The isolated reports of adverse health effects in the direct evidence could not be convincingly attributed to wind farm exposure. This was mainly due to the cross-sectional design of the available studies, inconsistent findings between studies, and the potential impact of bias, plausible confounders and chance on the observed results. Although it was clear that self-reported adverse health effects occurred in the vicinity of wind turbines, these effects did not differ by the purported degree of exposure to wind turbine noise i.e. estimated SPL (dose-responsiveness). Degree of exposure, as measured by *distance* from a wind turbine (dichotomised into 'near' and 'far') did affect mental health in one small study, although this finding was inconsistent with the non-statistically significant results reported from four other studies that measured stress, irritability, anxiety and depression in study participants.

A dose-response relationship was apparent between wind turbine proximity and the possibly health related effects of self-reported sleep quality, sleep disturbance and quality of life. However, there is a possibility that the associations with sleep quality, sleep disturbance and quality of life are confounded by annoyance and other factors that determine it. Annoyance appeared to be more related to turbine visibility and lack of economic benefit than to wind turbine noise[44] (see page 163 for further detail).

It could not be determined from the scant evidence available whether any of the effects studied except, perhaps, sleep disturbance would be reversible in the absence of wind turbine exposure. Equally, it was uncertain whether there is a clear mechanism of action by which wind turbine exposure can cause adverse health effects. The mechanistic evidence reviewed did indicate that shadow flicker and ELF EMR exposure could theoretically have physiological impacts on humans; that is, respectively, epileptic seizures in photosensitive individuals and possibly childhood leukaemia. However, the type of shadow flicker and extent of ELF EMR exposure produced by wind turbines is likely to be different from that considered in the parallel research evidence that was conducted in the laboratory or field setting. The flicker frequency and colour investigated in the laboratory setting was different from that produced by wind turbines. Similarly, from the scant evidence available it would appear that the degree of ELF EMR exposure around wind turbines was unlikely to be higher

[44] measured by estimated SPL

than that produced by general electrical appliances. Further evidence is therefore needed to determine possible mechanisms of action.

There was no scientifically accepted mechanism by which ILFN could cause adverse health effects in humans in the limited mechanistic evidence collated for this review. Further, given the recent South Australian Environment Protection Authority report on noise levels in the vicinity of wind turbines (Evans, Cooper & Lenchine 2013), the available laboratory (parallel) evidence is unlikely to be applicable as it primarily tested ILFN at high SPLs (>80 dB) and found inconsistent effects of ILFN on the intermediate physiological measures taken from study participants. Health outcomes were not measured.

Table 39 Assessing the causal hypothesis using the modified Bradford Hill Guidelines

| Type of evidence | Causal indicator | Demonstrated? |
|---|---|---|
| **Direct** *(Assesses the impact of wind turbine exposure on health outcomes)* | • Size of effect not attributable to plausible confounding | No. Where associations with wind turbine exposure were observed, they were generally weak and attributable to other factors. |
| | • Appropriate temporal proximity—cause precedes effect and effect occurs after a plausible interval | No. All studies were cross sectional and it was not determined whether exposure preceded onset of observed effects. |
| | • Appropriate spatial proximity—health effect occurs at same site as exposure | Yes. Self-reported health effects occurred near wind turbines. |
| | • Dose-responsiveness | Uncertain. There was no dose-response effect for health effects but there was evidence of increases in health-related (sleep disruption/quality of life) and relevant non-health-related effects (annoyance) by degree of estimated noise exposure. |
| | • Reversibility | Uncertain. One study reported reversibility of effect on sleep when moving away from proximity to wind turbines |
| **Mechanistic** *(Investigates the mechanisms that are* | • Evidence for a mechanism of action (biological, chemical, mechanical) | Uncertain. Plausible mechanisms were not demonstrated in the epidemiological studies or the few |

| Type of evidence | Causal indicator | Demonstrated? |
|---|---|---|
| *supposed to connect wind turbine exposure to health outcomes)* | | experimental studies in humans that reported on health or relevant non-health endpoints. |
| | • Coherence | Uncertain. Relevant current scientific knowledge as to possible mechanisms was not reviewed to the extent needed to make a judgement as to coherence. |
| **Parallel** *(Comprises related studies that have similar results)* | • Replicability | No. Similar study protocols were used across some wind turbine studies (e.g. SWE-00, SWE-05, NL-07) but adverse health effects were not replicated. Health effects were not measured in the "emission" laboratory and field studies. |
| | • Similarity | No. The exposures considered in the laboratory and field studies were either not reported or differed from those likely to be produced by wind turbines. |
| | • Applicability | Possible. Since European and North American countries have a longer history of, and more extensive, wind turbine development and a greater population density than Australia, it is possible that wind turbine exposure in Australia is qualitatively and quantitatively different from the exposures contributing most evidence. |

Source: Howick, Glasziou and Aronson (2009)

# ALTERNATIVE EXPLANATIONS FOR REPORTED ASSOCIATIONS

## *BQ6. IS THERE EVIDENCE THAT THERE ARE CONFOUNDING FACTORS OR EFFECT MODIFIERS THAT MIGHT EXPLAIN THE ASSOCIATION OF WIND TURBINES WITH ADVERSE HEALTH EFFECTS?*

### Attitudes towards wind farms

The studies included in the systematic review consistently found that proximity to wind turbines was related to annoyance, with three studies showing that level of annoyance is a stronger predictor of sleep disturbance, tension/stress and irritability than estimated wind turbine noise exposure *per se*.

Those who had a negative attitude to wind farms in general had 13.4 times the odds of being annoyed by noise from wind turbines than those who were not negative about wind farms (95%CI 6.03, 29.59) (Pedersen et al. 2007). Given that these results are from a cross-sectional study, it is not possible to determine whether attitudes to wind farms were stable and a predictor of annoyance, or whether noise annoyance had an impact on general attitudes towards wind farms. The association between how people view the appearance of wind turbines ('visual attitude', i.e. beautiful or ugly) and annoyance was strong, with a negative visual attitude increasing the odds of annoyance by more than 14 times (OR=14.4, 95%CI 6.37, 32.44).

### Visibility of turbines

The visibility of turbines strongly influenced whether respondents were annoyed by the noise of wind turbines or not. When individuals could see at least one wind turbine, they had almost 11 times the odds of being annoyed by the sound of it (see Table 24) (Pedersen et al. 2007). This association was strongly influenced by the visual attitude of the individuals; that is, whether they considered wind turbines to be aesthetically beautiful and natural, or ugly and unnatural. Visual attitude was a stronger determinant of noise annoyance in those who could see wind turbines than in those who could not (Pedersen & Larsman 2008).

### Financial gain from the site of turbines

Pedersen et al. (2009) reported that very few people who gained financially from wind turbines reported annoyance due to noise (3/100), although perception of the noise level was the same regardless of financial gain. They hypothesised that those who benefit financially may have a positive appraisal of the sound as it signifies profit, and also that those who are not benefiting financially from the wind turbines may have resentment against their neighbours who are, which could increase the difference in the levels of annoyance.

## Community decision-making on site of turbines

There was no direct evidence that community decision-making regarding the site of wind turbines influenced reported health outcomes within that community. However, Ellenbogen et al. (2012) note that effective public participation in, and direct benefits from, wind energy projects (such as receiving electricity from the neighbouring wind turbines) have been shown to result in less annoyance in general and better public acceptance overall. This would be consistent with the findings of van den Berg et al. (2008), who reported that the level of annoyance with wind turbine noise was lower in people who received financial benefit from the wind farm. They hypothesised that one of the mechanisms of this finding may be that those who gained financially may have had a measure of control over the location of the wind turbines.

## Age and design of turbines

None of the studies that assessed the impact of wind turbines on health assessed whether the age or design of the turbine influenced the results. However, it is noted from other sources that older wind turbines that used gears were noisier than newer turbines, which do not have a gear box (Hall, Ashworth & Shaw 2012).

## Nocebo effect

In the limited literature linking adverse health outcomes to wind farms, there was no evidence identified that considered health effects or related non-health effects (e.g. annoyance) could be due to expectation effects, or nocebo effects (negative placebo effects) (Häuser, Hansen & Enck 2012). It has been reported that soon after a wind farm project has been made public, local residents have been contacted by outside groups who provide information on the range of supposed negative effects of wind farms (Hall, Ashworth & Shaw 2012). There is therefore a risk that prior expectations towards wind farms could be negative, increasing the likelihood of individuals experiencing adverse effects (i.e. through a nocebo effect), either being sensitive to the effects they have been warned about, or attributing normally occurring health problems to the presence of wind turbines.

## LIMITATIONS IN THE EVIDENCE-BASE AND SUGGESTIONS FOR FURTHER RESEARCH

Although a very comprehensive search for both unpublished ('grey') and published ('black') literature on the adverse health effects of wind turbines was conducted, it cannot be excluded that some evidence may have been missed. Study authors may have chosen not to submit their work to a public forum or those responsible for research publication may have chosen not to publish the work. This can occur when the result of a study is a 'null result' i.e. there is no effect found. This type of publication bias tends to be a problem that affects the 'black' literature.

Present evidence on the association of exposure to wind turbines and adverse health effects appears to be very limited. There is no consistent evidence that adverse health effects are caused by exposure to wind turbine noise. There is, though, consistent—albeit probably confounded—evidence that noise from wind turbines is associated with annoyance, and reasonably consistent evidence that it is associated with sleep disturbance and poorer quality of life. None of this evidence is sufficient to establish a cause-and-effect relationship. While no research has directly addressed the association between infrasound from wind turbines and health effects, the possibility of such an association cannot be excluded on present evidence.

While, *a priori*, the probability that there are material health effects consequent on residence at a reasonable distance from wind turbines could be judged as low, concern has been expressed by people who live near wind turbines about perceived impacts on their health (Senate Community Affairs References Committee 2011). Given these subjective experiences and the limited research evidence summarised above, further and better research on the relationship between noise from wind turbines and health, sleep and quality of life is warranted.

There are several elements of research that would greatly assist making stronger conclusions regarding the health effects of wind farms. These aspects include:

- comparative data; that is, measuring health outcomes in groups who have not been exposed to wind turbines and comparing it with data collected from groups who have been exposed to wind turbines, ideally collected in the same time period and at the same time points.
- prospective collection of data to enable temporal effects to be examined; that is, measuring the health status of residents prior to wind turbine installation and again afterwards
- response from a sample representative of all those exposed (i.e. not only those who have a health complaint but, ideally, at least a 70% response rate from those approached), in order to be externally generalisable
- large enough samples to allow confidence that the effects are not due to chance

- health examinations carried out by professionals rather than self-reported, to increase the objectivity of outcomes
- health effects reported with participants and interviewers masked to study intent, to minimise bias
- objective measurements of exposure (such as volume of noise at the place of residence, distance to nearest wind turbine), rather than modelled measurements
- statistical analyses adjusted for cluster effects and multiple comparisons.

One of the largest identified problems with the literature is the sample selection bias in the studies. Although the participants may have been recruited from relevant populations, and the better quality studies have attempted to gain data from a cross-section of people exposed and non-exposed to wind farms, the response rates were very poor. There is, therefore, an increased probability of biased comparisons between exposed and unexposed groups and a high risk that those who responded to the surveys are not representative of the whole community (both exposed and non-exposed). Rather, they have self-selected to respond to the survey because they are experiencing adverse events. The field of wind farm research would be greatly improved by comparative research that uses a mix of strategies to improve rates of response. A reasonable study design would be a prospective cohort study, retrieving data from individuals who live in areas where a wind farm is being proposed to be built and from similar communities where a wind farm is not going to be built.

A simpler study design, which would also provide useful information, would be a historical control study, comparing data before and after the introduction of a wind farm. Health data could be gathered from sources such as from general practitioners' records (e.g. the BEACH database), to see whether the rates of health complaints go up with the introduction of the wind farm, after adjustment for potential confounders. Alternatively, a retrospective cohort study could be conducted where data are also obtained from a control group over the same time period, with comparative baseline rates of health complaints and similar demographics to control for the effect of time.

# ONGOING RESEARCH

## International research

The limited availability of robust, peer-reviewed scientific studies on the health effects of wind turbines/farms has stimulated some government health authorities, such as Health Canada, to begin conducting independent research. Health Canada argues that lack of prevalence data on community complaints and self-reported health impacts from studies with strong methodological designs are significant barriers to providing advice on noise impacts from wind turbines. If such data were available, it is likely that understanding of the concern about wind turbine noise among affected communities would be improved. This could then be compared with the prevalence of similar health concerns in communities that are not situated near wind turbines (Health Canada 2012).

Health Canada is now undertaking a cross-sectional field study to compare self-reported health impacts and symptoms of illness (25-minute interviews) against *objective* biomarkers of stress and the sound levels produced by wind turbines. The expected publication date for this study is late 2014 and will include 2000 dwellings at setback distances ranging from less than 500 m to greater than 5 km from 8–12 wind farms. Collected data will be correlated with model estimates of wind turbine noise (validated against actual measurements) so that potential relationships to reported health symptoms can be reliably determined. Specifically, the objective data under evaluation will include (Health Canada 2012, 2013):

- automated blood pressure measurements;
- 90-day retrospective cortisol levels based on hair samples;
- actigraphic measurements of sleep over 7 consecutive days (synchronised with wind turbine operational data and estimates of indoor wind turbine sound exposure); and
- environmental sound measurements, including low-frequency noise, inside and outside a subsample of homes (to validate parameters for accurate sound level modelling).

Importantly, unlike the peer-reviewed literature considered in our review, Health Canada will undertake measures to mitigate the effects of participation bias that are likely to influence the results in the absence of a response rate below the 70–75% range. By targeting all dwellings within the highest wind turbine sound exposure categories, random sampling of dwellings at more distant sound exposure categories, and random sampling of the one subject per home that participates in the survey, it is anticipated that bias due to self-selection should be reduced as much as possible. As part of the questionnaire process, the study protocol specifies collection of information that will allow Health Canada to determine the extent to which bias may influence results. The potential for entry of bias that relates to time of day when visits are made to conduct questionnaires has been planned for by specifying that home visits should be made at all times of the day. Statistical analyses to assess any systematic differences that may exist in subjects that participate fully, partially or not at all are also planned. For example, an analysis by distance to the closest turbine can be done to reveal a potential bias in the sample. Despite these measures, however, Health Canada has acknowledged that the extent to which non-response may impact their study cannot be determined *a priori.*

## Australian research

The Environment Protection Authority of South Australia (Evans, Cooper & Lenchine 2013) has conducted research on the levels of infrasound near wind farms and other environments, with further study of similar design ongoing. Environments other than those within the vicinity of wind farms were included in order to compare background infrasound levels with the levels that are measured in areas near wind farms when turbines are both operational and non-operational. While these findings are an important part of ongoing research, the relationship of these levels with objective measures of health is yet to be studied in Australia. Objective measures of exposure other than sound (i.e. flicker and ELF EMR) are also lacking, and exploration of these exposures and health status (pre-exposure and post-exposure) may be helpful in drawing conclusions about whether there is a relationship between wind turbines and health. As suggested above, the study design that would be most useful is a prospective cohort study. A historical control study could also be designed in order to examine potential associations between observed changes in health status and exposure while reducing, or at least quantifying, the likelihood that factors other than the exposure are confounding the findings or introducing bias. An approach similar to the Health Canada study on wind turbines and health could also be adopted, noting transparently the limitations of this approach. Following availability of robust, relatively homogenous data from Australia, Canada and elsewhere, the results of a possible pooled analysis of health outcomes would be useful for informing future policy recommendations.

# CONCLUSIONS

In summary, the systematic review found no consistent evidence that noise from wind turbines, whether estimated in models or using distance as a proxy, is associated with self-reported human health effects. The quality and quantity of the available evidence was limited.

Wind turbine noise—whether estimated in models or using distance as a proxy—was associated with annoyance, and often associated with sleep disturbance and poorer sleep quality and quality of life. However, there are concerns as to the strength and validity of these reported associations in the available evidence (see below).

Shadow flicker produced by wind turbines was found to be associated with annoyance in one small study, but health effects were not measured. There were no studies identified that investigated the impact on health of the electromagnetic radiation produced by wind turbines.

## Do wind turbines cause adverse health effects in humans?

To evaluate the strength of the evidence for a cause-and-effect relationship between wind turbines and adverse human health and health-related effects, the totality of the evidence was assessed in terms of the modified Bradford Hill Guidelines (Table 5, page 40).

The reported effects in the studies did occur near wind turbines (spatial proximity). However, with the exception of annoyance, sleep quality or disturbance and quality of life—which are possibly related—there was no consistent association between adverse health effects and estimated noise from wind turbines. Any isolated associations that were observed could have been due to plausible confounding or a spurious result from undertaking multiple statistical tests. It was not possible to determine whether any of the associations of wind turbine exposure with self-reported health effects occurred before or after first exposure to wind turbines (temporal proximity) because of the cross-sectional nature of the available studies. From the reported data, there was no dose–response relationship observed between estimated noise exposure (modelled SPL or distance from a wind turbine) and direct human health effects.

A dose–response relationship between wind turbine proximity and possibly health-related effects such as sleep disturbance, poor sleep quality and quality of life was apparent; that is, these effects were less common as the estimated SPL reduced or distance from wind turbines increased. However, the studies measuring sleep disturbance, sleep quality and quality of life often did not control for factors that may have confounded the results, such as annoyance and other factors that determine it. In the studies measuring noise annoyance there was a stronger association with turbine visibility or lack of economic benefit than with estimated sound pressure level. Evidence of reversibility was present in one small study. Participants in this study recalled less sleep disturbance when they were away from wind turbines. The participants knew the purpose of the study was to investigate wind turbine noise.

The information addressing the background questions did not strengthen the evidence base for an association between health, or health-related, effects and exposure to wind turbines. Possible mechanisms by which wind turbines could harm human health—and which were coherent with existing scientific theory—were plausible for shadow flicker and ELF EMR exposure, but were of uncertain applicability to the wind turbine context. A mechanism by which ILFN could harm human health could not be determined. There was no consistent association observed between ILFN and intermediate physiologic effects (e.g. blood pressure) in the laboratory setting. Health outcomes were not measured.

The quality and quantity of evidence available to address the questions posed in this review was limited. The evidence considered does not support the conclusion that wind turbines have direct adverse effects on human health, as the criteria for causation have not been fulfilled. Indirect effects of wind farms on human health through sleep disturbance, reduced sleep quality, quality of life and perhaps annoyance are possible. Bias and confounding could, however, be possible explanations for the reported associations upon which this conclusion is based.

# REFERENCES

Ahlbom, I, Cardis, E, Green, A, Linet, M, Savitz, D & Swerdlow, A 2001, 'Review of the epidemiologic literature on EMF and health', *Environmental Health Perspectives*, vol. 109, no. Suppl 6, p. 911.

Åkerstedt, T, Arnetz, B, Ficca, G, Paulsson, LE & Kallner, A 1999, 'A 50-Hz electromagnetic field impairs sleep', *Journal of Sleep Research*, vol. 8, no. 1, pp. 77–81.

Alford, BR, Jerger, J, Coats, A, Billingham, J, French, B & McBrayer, RO 1966, 'Human tolerance to low frequency sound', *Journal of Occupational and Environmental Medicine*, vol. 8, no. 11, p. 620.

Ali, A, Alam, F, Djamovski V & Watkins, S 2011, 'A review of power generation from wind in Australia', *Proceedings of the International Conference on Mechanical Engineering 2011 (ICME2011)*, 17-19 December 2011, Dhaka, Bangladesh.

Alves-Pereira, M & Castelo Branco, NA 2007, 'Vibroacoustic disease: biological effects of infrasound and low-frequency noise explained by mechanotransduction cellular signalling', *Progress in Biophysics and Molecular Biology*, vol. 93, no. 1–3, pp. 256–79.

Armstrong, B, Aitken, J, Sim, M & Swan, N 2007, *Breast cancer at the ABC Toowong Queensland: Final report of the Independent Review and Scientific Investigation Panel*.

Australian Government 2012, *The social and economic impact of rural wind farms: response to the Senate Community Affairs References Committee Report*, Canberra.

Azizi, MH 2010, 'Occupational noise-induced hearing loss', *International Journal of Occupational and Environmental Medicine,* vol. 1, no. 3, pp. 116–123.

Babisch, W 2002, 'The noise/stress concept, risk assessment and research needs', *Noise Health*, vol. 4, no. 16, 1–11.

Bakker, RH, Pedersen, E, van den Berg, GP, Stewart, RE, Lok, W & Bouma, J 2012, 'Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress', *Science of the Total Environment*, vol. 425, pp. 42–51.

Barry H & Yeo S 2011, *Review of the Australian wind industry 2011*, The Clean Energy Council, viewed 17 July 2013, <http://www.cleanenergycouncil.org.au/resourcecentre/reports/previous-reports.html>

Beranek, LL & Ver, IL 1992, *Noise and vibration control engineering: principles and applications,* John Wiley & Sons, Inc., 814 pp., vol. 1; cited in Rogers, Manwell and Wright (2006).

Berglund, B, Hassmen, P & Job, RFS 1996, 'Sources and effects of low-frequency noise', *Journal of the Acoustical Society of America*, vol. 99, p. 2985.

Buysse, DJ, Reynolds, CF, Monk, TH, Berman, SR & Kupfer, DJ 1989, 'The Pittsburgh Sleep Quality Index (PSQI): a new instrument for psychiatric research and practice', *Psychiatry Research*, vol. 28, no. 2, pp. 193–213.

Danielsson, AKE & Landstrome, ULF 2009, 'Blood pressure changes in man during infrasonic exposure', *Acta Medica Scandinavica*, vol. 217, no. 5, pp. 531–535.

Dang-Vu, TT, McKinney, SM, Buxton, OM, Solet, JM & Ellenbogen, JM 2010, 'Spontaneous brain rhythms predict sleep stability in the face of noise', *Current Biology*, vol. 20, no. 15, pp. R626-7.

Davies H, Kamp IV 2012, 'Noise and cardiovascular disease: a review of the literature 2008–2011', *Noise Health*, vol. 14, pp. 287–291.

Downs, SH & Black, N 1998, 'The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions', *Journal of Epidemiology and Community Health*, vol. 52, no. 6, pp. 377–384.

Elgoyhen, AB & Langguth, B 2010, 'Pharmacological approaches to the treatment of tinnitus', *Drug Discovery Today*, vol. 15, no. 7–8, pp. 300–305.

Ellenbogen, JM, Grace, S, Heiger-Bernays, WJ, Manwell, JF, Mills, DA, Sullivan, KA & Weisskopf, MG 2012, *Wind turbine health impact study: Report of Independent Expert Panel*, Massachusetts Department of Public Health, Massachusetts.

Elwood, MJ 2010, *Critical appraisal of epidemiological studies and clinical trials*, review, published online 2009, Oxford University Press, Oxford.

EPHC 2010, *National Wind Farm Development Guidelines – draft*, Department of the Environment, Water, Heritage and the Arts, Environment Protection and Heritage Council, Adelaide.

Eriksson, C, Rosenlund, M, Pershagen, G, Hilding, A, Östenson, CG & Bluhm, G 2007, 'Aircraft noise and incidence of hypertension', *Epidemiology*, vol. 18, no. 6, pp. 716–721.

European Wind Energy Association 2009, *Wind energy – the Facts: a guide to the technology, economics and future of wind power, Part IV: Industry & Markets*, Routledge, viewed 21 November 2012, <http://www.wind-energy-the-facts.org/en/part-4-industry--markets/industry--markets.html>.

Evans, T, Cooper, J & Lenchine, V 2013, *Infrasound levels near windfarms and in other environments*, Environment Protection Authority South Australia, viewed April 2013, <http://www.epa.sa.gov.au/xstd_files/Noise/Report/infrasound.pdf>.

Fuchs, GL, Verzini, AM & Nitardi, H 1995, 'Preliminary search of thresholds and effects of very-low-frequency sounds on man', *International Journal of Environmental Studies*, vol. 49, no. 1, pp. 1–11.

Grogg, K 2005, 'Harvesting the wind: the physics of wind turbines', *Physics and Astronomy Comps Papers*, Carleton College, Minnesota.

Guerrini, R & Genton, P 2004, 'Epileptic syndromes and visually induced seizures', *Epilepsia*, vol. 45, no. s1, pp. 14–18.

Hall, N, Ashworth, P & Shaw, H 2012, *Exploring community acceptance of rural wind farms in Australia: a snapshot*, CSIRO Science into Society Group.

Harding, G, Harding, P & Wilkins, A 2008, 'Wind turbines, flicker, and photosensitive epilepsy: characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them', *Epilepsia*, vol. 49, no. 6, pp. 1095–1098.

Harry, A 2007, *Wind turbines, noise and health*, Electronic self-published report, Accessed 18 January 2013, <http://www.wind-watch.org/documents/wind-turbines-noise-and-health/>.

Hau, E 2008, *Wind turbines: fundamentals, technology, application, economics*, Springer Verlag, Berlin, cited in Roberts et al. (2009).

Haugen, KMB 2011, *International review of policies and recommendations for wind turbine setbacks from residences: setbacks, noise, shadow flicker, and other concerns*, Minnesota Department of Commerce, Minnesota.

Häuser, W, Hansen, E., Enck, P 2012, 'Nocebo phenomena in medicine: their relevance in everyday clinical practice', *Deutsches Aerzteblatt International*, vol. 109, no. 26, pp. 459–465.

Hawkins, T 2012, *Fact sheet: wind turbines and low frequency sound*, Expert opinion: wind energy consultant, viewed 15 November 2012, <http://media.beyondzeroemissions.org/wind_turbine_sound_FactSheet.pdf>.

Health Canada 2012, *Health impacts and exposure to wind turbine noise: research design and noise exposure assessment*, viewed April 2013, <http://www.hc-sc.gc.ca/ewh-semt/consult/_2012/wind_turbine-eoliennes/research_recherche-eng.php>.

——— 2013, *Health impacts and exposure to sound from wind turbines: updated research design and sound exposure assessment*, viewed April 2013, <http://www.hc-sc.gc.ca/ewh-semt/consult/_2013/wind_turbine-eoliennes/research_recherche-eng.php>.

Hillier, S, Grimmer-Somers, K, Merlin, T, Middleton, P, Salisbury, J, Tooher, R & Weston, A 2011, 'FORM: an Australian method for formulating and grading recommendations in evidence-based clinical guidelines', *BMC Medical Research Methodology*, vol. 11, p. 23.

Howick, J, Glasziou, P & Aronson, JK 2009, 'The evolution of evidence hierarchies: what can Bradford Hill's 'guidelines for causation' contribute?', *Journal of the Royal Society of Medicine*, vol. 102, no. 5, pp. 186–194.

HPA 2012, *NRPB Archive*, UK Health Protection Agency, Radiation Protection Division, viewed 15 November 2012, <http://www.hpa.org.uk/Publications/Radiation/NPRBArchive/>.

ICNIRP 2003, *Exposure to static and low frequency electromagnetic fields, biological effects and health consequences*, ed. by Rüdiger Matthes, International Commission on Non-Ionizing Radiation Protection, Munich, Germany.

ICNIRP 2012, *EMF publications*, International Commission on Non-Ionizing Radiation Protection, viewed 15 November 2012, <http://www.icnirp.org/PubEMF.htm>.

International Epidemiological Association 2008, *Dictionary of epidemiology*, ed. by M Porta, Oxford University Press, Oxford.

Iser, D 2004, *Survey on wind power station effects*, Self-published report, South Gippsland, Victoria, Public submission to the National Health and Medical Research Council.

Jacobsen, F, Poulsen, T, Rindel, J, Gade, A & Ohlrich, M 2011, *Fundamentals of acoustics and noise control*, Department of Electrical Engineering, Technical University of Denmark, Denmark.

Jakobsen, J 2005, 'Infrasound emission from wind turbines', *Low Frequency Noise, Vibration and Active Control*, vol. 24, no. 3, pp. 145–155.

Johansen, C 2000, 'Exposure to electromagnetic fields and risk of central nervous system disease in utility workers', *Epidemiology*, vol. 11, no. 5, pp. 539–543.

Johansen, C, Feychting, M, Møller, M, Arnsbo, P, Ahlbom, A & Olsen, JH 2002, 'Risk of severe cardiac arrhythmia in male utility workers: a nationwide Danish cohort study', *American Journal of Epidemiology*, vol. 156, no. 9, pp. 857–861.

Johansen, C & Olsen, JH 1998, 'Mortality from amyotrophic lateral sclerosis, other chronic disorders, and electric shocks among utility workers', *American Journal of Epidemiology*, vol. 148, no. 4, pp. 362–368.

Johansen, C, Raaschou-Nielsen, O, Skotte, J, Thomsen, BL & Olsen, JH 2002, 'Validation of a job-exposure matrix for assessment of utility worker exposure to magnetic fields', *Applied Occupational and Environmental Hygiene*, vol. 17, no. 4, pp. 304–310.

Karipidis, KK & Martin, LJ 2005, *Pilot study of residential power frequency magnetic fields in Melbourne*, October 2005, Australian Radiation Protection and Nuclear Safety Agency Technical Report 142, viewed March 2013, <http://www.arpansa.gov.au/pubs/technicalreports/tr142.pdf>.

Kheifets, L & Shimkhada, R 2005, 'Childhood leukemia and EMF: review of the epidemiologic evidence', *Bioelectromagnetics*, vol. Suppl 7, pp. S51–S59.

Kim, YS & Cho, YS 2001, 'Exposure of workers to extremely low-frequency magnetic fields and electric appliances', *Journal of Occupational Health*, no. 43, pp. 141–149.

Knopper, LD & Ollson, CA. 2011, 'Health effects and wind turbines: a review of the literature', *Environmental Health*, vol. 10, p. 78.

Krogh, CME, Gillis, L, Kouwen, N & Aramini, J 2011, 'WindVOiCe, a self-reporting survey: adverse health effects, industrial wind turbines, and the need for vigilance monitoring', *Bulletin of Science, Technology & Society*, vol. 31, no. 4, pp. 334–345.

Laszlo, HE, McRobie, ES, Stansfeld, SA & Hansell, AL 2012, 'Annoyance and other reaction measures to changes in noise exposure: a review', *Science of the Total Environment*, vol. 435–436 pp. 551–562.

Leventhall, G 2006, 'Infrasound from wind turbines-fact, fiction or deception', *Canadian Acoustics*, vol. 34, no. 2, p. 29.

Liberati, A, Altman, DG, Tetzlaff, J, Mulrow, C, Gotzsche, PC, Ioannidis, JP, Clarke, M, Devereaux, PJ, Kleijnen, J & Moher, D 2009, 'The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration', *British Medical Journal*, vol. 339, p. b2700.

Lim, DJ & Melnick, W 1971, 'Acoustic damage of the cochlea: a scanning and transmission electron microscopic observation', *Archives of Otolaryngology—Head & Neck Surgery*, vol. 94, no. 4, pp. 294–305.

LNW 2002, *Windenergieanlagen und immissionsschutz*, Landesumweltamt Nordrhein-Westfalen, viewed 19 November 2012, <http://www.lanuv.nrw.de/veroeffentlichungen/materialien/mat63/mat63_web.pdf>

McFadden, JD 2010, *Wind turbines: a brief health overview*, Wisconsin Wind Siting Council, viewed 20 November 2012, <http://www.oregon.gov/energy/Siting/docs/MWP/MWPHealthOverviewPowerPoint.pdf>.

Merlin T, Weston A & Tooher R 2009, 'Extending an evidence hierarchy to include topics other than treatment: revising the Australian ‘levels of evidence’', *BMC Medical Research Methodology*, vol. 9, no. 34

Mills, JH, Osguthorpe, JD, Burdick, C, Patterson, J & Mozo, B 1983, 'Temporary threshold shifts produced by exposure to low-frequency noises', *Journal of the Acoustical Society of America*, vol. 73, p. 918.

Morris, M 2012, 'Waterloo Wind Farm survey', Electronic self-published report, Accessed 18 January 2013, <www.wind-watch.org/news/wp-content/uploads/2012/07/Waterloo-Wind-Farm-Survey-April-2012-Select-Committee.pdf>.

National Health and Medical Research Council 2010, *Wind turbines and health: a rapid review of the evidence*, NHMRC, Canberra, ACT, viewed August 2012, <http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/evidence_review_wind_turbines_health%20.pdf>.

——— 2010a, *NHMRC public statement: wind turbines and health*, NHMRC, Canberra, ACT, viewed August 2012,

<http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/new0048_public_statement_wind%20turbines_and_health.pdf>.

NHMRC 2000, *How to use the evidence: assessment and application of scientific evidence*, National Health and Medical Research Council, Canberra.

——— 2008, *NHMRC additional levels of evidence and grades for recommendations for developers of guidelines: Stage 2 consultation, early 2008 – end June 2009*, National Health and Medical Research Council, Canberra, ACT, viewed 6 August 2008, <http://www.nhmrc.gov.au/guidelines/consult/consultations/add_levels_grades_dev_guidelines2.htm>.

NIEHS 2012, *Electric & magnetic fields*, National Institute of Environmental Health Sciences, viewed 15 November 2012, <http://www.niehs.nih.gov/health/topics/agents/emf/>.

NINDS 2012, *NINDS epilepsy information page*, National Institute of Neurological Disorders and Stroke, viewed 15 November 2012, <http://www.ninds.nih.gov/disorders/epilepsy/epilepsy.htm>.

Nissenbaum, M, Aramini, J & Hanning, C 2011, 'Adverse health effects of industrial wind turbines: a preliminary report', Proceedings of 10th International Congress on Noise as a Public Health Problem (ICBEN), 2011, Curran Associates, London, UK.

Nissenbaum M, Aramini J & Hanning C 2012, 'Effects of industrial wind turbine noise on sleep and health', *Noise & Health*, vol. 14, no. 60, pp. 237–243.

O'Neal, RD, Hellweg, RD & Lampeter, RM 2011, 'Low-frequency noise and infrasound from wind turbines', *Noise Control Engineering Journal*, vol. 59, no. 2, pp. 135–157.

Pedersen, E 2011, 'Health aspects associated with wind turbine noise: results from three field studies', *Noise Control Engineering Journal*, vol. 59, no. 1, pp. 47–53.

Pedersen, E & Larsman, P 2008, 'The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines', *Journal of Environmental Psychology*, vol. 28, no. 4, pp. 379–389.

Pedersen, E & Persson Waye, K 2004, 'Perception and annoyance due to wind turbine noise: a dose-response relationship', *Journal of the Acoustical Society of America*, vol. 116, no. 6, pp. 3460–3470.

——— 2007, 'Wind turbine noise, annoyance and self-reported health and well-being in different living environments', *Occupational and Environmental Medicine*, vol. 64, no. 7, pp. 480–486.

Pedersen, E, van den Berg, F, Bakker, R & Bouma, J 2009, 'Response to noise from modern wind farms in The Netherlands', *Journal of the Acoustical Society of America*, vol. 126, p. 634.

Persson Waye, K 2004, 'Effects of low-frequency noise on sleep', *Noise Health*, vol. 6, no. 23, pp. 87–91.

Phillips, C 2011, 'Properly interpreting epidemiologic evidence about the health effects of industrial wind turbines on nearby residents', *Bulletin of Science, Technology & Society*, vol. 31, pp. 303–315.

Phipps R, AM, McCoard S, Fisher R. 2008, *Visual and noise effects reported by residents living close to Manawatu wind farms: preliminary survey results*, <http://www.wind-watch.org/documents/visual-and-noise-effects-reported-by-residents-living-close-to-manawatu-wind-farms-preliminary-survey-results/>.

Pierpont, N 2009, *Wind turbine syndrome: a report on a natural experiment*, K-Selected Books, Santa Fe, New Mexico, pp. 66.

Pohl, J, Faul, F & Mausfeld, R 1999, *Annoyance due to shadow flicker from wind turbines-laboratory pilot study (with appendix) and field study (with appendix).* Institute of Psychology, Christian-Albrechts-University Kiel, Germany, cited in Ellenbogen (2012).

Prasher, D 2009, 'Is there evidence that environmental noise is immunotoxic?', *Noise Health*, vol. 11, no. 44, p. 151.

Raymond, J 2012, *Wind turbine power calculations*, viewed 15 November 2012, <www.ajdesigner.com/phpwindpower/wind_generator_power.php>.

Rideout, K, Copes, R & Bos, C 2010, *Wind turbines and health*, National Collaborating Centre for Environmental Health, Vancouver, viewed 19 November 2012, <http://www.ncceh.ca/en/practice_policy/ncceh_reviews/wind_turbines>.

Roberts, M & Roberts, J 2009, *Evaluation of the scientific literature on the health effects associated with wind turbines and low frequency sound*, Wisconsin Public Service Commission, Illinois, USA, viewed 15 November 2012, <http://www.maine.gov/dhhs/mecdc/environmental-health/documents/wind-turbine-wisconsin-assessment.pdf>.

Rogers, AL, Manwell, JF & Wright, S 2006, *Wind turbine acoustic noise*, Renewable Energy Research Laboratory, University of Massachusetts, Amherst.

Seidman, MD & Standring, RT 2010, 'Noise and quality of life', *International Journal of Environmental Research and Public Health*, vol. 7, no. 10, pp. 3730–3738.

Selander J, Bluhm G, Nilsson M, Hallqvist J, Theorell T, Willix P, Pershagen G 2013, 'Joint effects of job strain and road-traffic and occupational noise on myocardial infarction', *Scandinavian Journal of Work, Environment and Health*, vol. 39, no. 2, pp. 195–203. doi: 10.5271/sjweh.3324. Epub 2012 Oct 2.

Selander, J, Nilsson, ME, Bluhm, G, Rosenlund, M, Lindqvist, M, Nise, G & Pershagen, G 2009, 'Long-term exposure to road traffic noise and myocardial infarction', *Epidemiology*, vol. 20, no. 2, pp. 272–279.

Senate Community Affairs References Committee 2011. *The social and economic impact of rural wind farms,* Commonwealth of Australia, pp. 20–28.

Shepherd, D, McBride, D, Welch, D, Dirks, KN & Hill, EM 2011, 'Evaluating the impact of wind turbine noise on health-related quality of life', *Noise Health*, vol. 13, no. 54, pp. 333–339.

Shirakawa, S, Funatsuka, M, Osawa, M, Fujita, M & Oguni, H 2001, 'A study of the effect of color photostimulation from a cathode-ray tube (CRT) display on photosensitive patients: the effect of alternating red–cyan flicker stimulation', *Epilepsia*, vol. 42, no. 7, pp. 922–929.

Smedley, ARD, Webb, AR & Wilkins, AJ 2009, 'Potential of wind turbines to elicit seizures under various meteorological conditions', *Epilepsia*, vol. 51, no. 7, pp. 1146–1151.

Smith, A 2010, 'Noise and health: why we need more research', presented at: InterNoise 2010: Noise and Sustainability, Lisbon, Portugal, 13–16 June 2010, *INCE InterNoise Conference Proceedings*. Indianapolis, IN: INCE – Institute of Noise Control Engineering, pp. 2641–2647.

Takigawa, H, Sakamoto, H & Murata, M 1991, 'Effects of infrasound on vestibular function', *Journal of Sound and Vibration*, vol. 151, no. 3, pp. 455–460.

Thorne, B 2011, 'The problems with "noise numbers" for wind farm noise assessment', *Bulletin of Science, Technology & Society*, vol. 31, no. 4, pp. 262–290.

Van den Berg, G 2004, 'Do wind turbines produce significant low-frequency sound levels', 11th International Meeting on Low Frequency Noise and Vibration and its Control, Maastricht, The Netherlands.

Van den Berg, G, Pedersen, E, Bouma, J & Bakker, R 2008, *Project WINDFARMperception: visual and acoustic impact of wind turbine farms on residents*, 2012/11/13/06:24:13, University of Groningen, FP6-2005-Science-and-Society-20, Specific Support Action, Project no. 044628, viewed 13 November 2012, <http://www.epaw.org/documents/WFp-final-1.pdf>.

van Kamp, I, Houthuijs, D, van Wiechen, C & Breugelmans, O 2007, ‘Environmental noise and mental health: evidence from the Schiphol monitoring program’, Institute of Noise Control Engineering, pp. 1177–1183, cited in Smith (2010).

Verkuijlen, E & Westra, C 1984, ‘Shadow hindrance by wind turbines’, Proceedings of the European Wind Energy Conference, October 1984, Hamburg, Germany.

Verrotti, A, Tocco, AM, Salladini, C, Latini, G & Chiarelli, F 2005, 'Human photosensitivity: from pathophysiology to treatment', *European Journal of Neurology*, vol. 12, no. 11, pp. 828–841.

Verzini, A, Skarp, A, Nitardi, H & Fuchs, G 1999, 'A laboratory experiment on very-low-frequency sounds effects', *Applied Acoustics*, vol. 57, no. 1, pp. 69–77.

Wagner, S, Bareiss, R & Guidati, G 1996, *Wind turbine noise*, Springer, Berlin, cited in Ellenbogen et al. (2012).

Wang, Z 2011, *Evaluation of wind farm noise policies in South Australia: a case study of Waterloo Wind Farm,* Masters dissertation, Discipline of Geography, Environment and Population, University of Adelaide, Adelaide, Accessed 18 January 2013, <http://www.wind-watch.org/news/wp-content/uploads/2012/07/Evaluation-of-Wind-Farm-Noise-Policies-in-South-Australia-Waterloo-Case-Study.pdf>.

Watanabe, T & Møller, H 1990, 'Low-frequency hearing thresholds in pressure field and in free field', *Journal of Low Frequency Noise and Vibration*, vol. 9, no. 3, pp. 106–115.

Waye, KP, Bengtsson, J, Rylander, R, Hucklebridge, F, Evans, P & Clow, A 2002, 'Low-frequency noise enhances cortisol among noise sensitive subjects during work performance', *Life Sciences*, vol. 70, no. 7, pp. 745–758.

Waye, KP, Clow, A, Edwards, S, Hucklebridge, F & Rylander, R 2003, 'Effects of nighttime low-frequency noise on the cortisol response to awakening and subjective sleep quality', *Life Sciences*, vol. 72, no. 8, pp. 863–875.

Wertheimer, N & Leeper, E. 1979, 'Electrical wiring configurations and childhood cancer', *American Journal of Epidemiology*, vol. 109, no. 3, pp. 273–284.

WHO 1948, *Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19–22 June 1946;* signed on 22 July 1946 by the representatives of 61 States (Official Records of the World Health Organization, no. 2, p. 100) and entered into force on 7 April 1948.

——— 1959, *Sixth report of the Expert Committee* on Mental *Health*, World Health Organization Technical Report Series, no. 171, Geneva, Switzerland.

——— 2002, *Establishing a dialogue on risks from electromagnetic fields*, World Health Organization, Geneva.

——— 2009, *Night Noise Guidelines for Europe*, World Health Organization, viewed April 2013, <http://www.euro.who.int/__data/assets/pdf_file/0017/43316/E92845.pdf>.

——— 2011, *Burden of disease from environmental noise*, World Health Organization, viewed April 2013, <http://www.euro.who.int/en/what-we-publish/abstracts/burden-of-disease-from-environmental-noise.-quantification-of-healthy-life-years-lost-in-europe>.

——— 2012a, *International Electromagnetic Fields Project*, World Health Organization, viewed 15 November 2012, <http://www.who.int/peh-emf/en/>.

——— 2012b, *What are electromagnetic fields? Typical exposure levels at home and in the environment*, World Health Organization, viewed 20 November 2012, <http://www.who.int/peh-emf/about/WhatisEMF/en/index3.html>.

——— 2012c, *What happens when you are exposed to electromagnetic fields?*, World Health Organization, viewed 20 November 2012, <http://www.who.int/peh-emf/about/WhatisEMF/en/index1.html>.

Wilkins, A, Veitch, J & Lehman, B 2010 'LED lighting flicker and potential health concerns: IEEE standard PAR1789 update', IEEE ECCE Congress, pp. 171–178.

Windrush Energy 2004, *The health effects of magnetic fields generated by wind turbines*, Windrush Energy, Toronto, viewed 20 November 2012, <http://www.windrush-energy.com/update%20Jul%2024/Appendix%20D%20-%20Magnetic%20Field%20Survey/Magnetic%20Field%20Report.pdf>.

# GLOSSARY AND ABBREVIATIONS

## Glossary[45]

| | |
|---|---|
| *A priori* | Relating to or denoting reasoning or knowledge that proceeds from theoretical deduction rather than from observation or experience. |
| Aerodynamic sound | Sound generated by turbulent motion or aerodynamic forces interacting with surfaces; for *wind turbines*, generated by the interaction of the blade trailing-edge, tip or surface with air turbulence (see Table 8 for a full description). |
| Amplitude | A measurement of the energy carried by a wave—the greater the amplitude of the wave, the higher the level of energy carried; for a sound wave, the greater the amplitude, the louder the sound. |
| Annoyance | An unpleasant mental state that is characterised by such effects as irritation and distraction from one's conscious thinking. |
| ANOVA* | Analysis of variance: a statistical technique that isolates and assesses the contribution of categorical independent variables to the variance of the mean of a continuous dependent variable. The observations are classified according to their categories for each of the independent variables, and the differences between the categories in their mean values on the dependent variable are estimated and tested for statistical significance. |
| Association* | Statistical dependence between two or more events, characteristics or other variables. An association is present if the probability of occurrence of an event or characteristic, or the quantity of a variable, varies with the occurrence of one or more other events, the presence of one or more other characteristics, or the quantity of one or more other variables. An association may be fortuitous or may be produced by various other circumstances; the presence of an association does not necessarily imply a causal relationship. In epidemiological and clinical research, the terms association and relationship may often be used interchangeably. |
| Audibility threshold | Also known as the absolute threshold of hearing, it is the minimum sound level of a pure tone that an average ear with normal hearing can register with no other sound present. |
| Audible sound | Sound that can be detected normally by the human ear; sound that falls within the nominal frequency range of 20–20,000 Hz (upper |

[45] All epidemiological terms (marked as *) in this Glossary have been defined using the International Epidemiological Association's (IEA's) *Dictionary of Epidemiology* (2008).

range limit declines with age) and with normal exposure levels.

Bias* — Systematic deviation of results or inferences from truth; processes leading to such deviation; an error in the conception and design of a study—or in the collection, analysis, interpretation, reporting, publication or review of data—leading to results or conclusions that are systematically (as opposed to randomly) different from the truth.

Biological plausibility* — The causal criterion or consideration that an observed, presumably causal, association is plausible on the basis of existing biomedical knowledge.

Black literature — An alternative term for peer-reviewed literature that has been published.

Blade glint — The visual effect of light reflecting off the rotating blade surface of a *wind turbine*; can theoretically result in a stroboscopic effect to an observer.

Broadband sound — When a sound is produced by a broad range of frequencies, it is generally called broadband (such as sound from a waterfall).

Case series* — A collection of patients with common characteristics used to describe some clinical, pathophysiological or operational aspect of a disease, treatment or diagnostic procedure. A case series does not include a comparison group and is often based on prevalent cases and a sample of convenience. Common selection biases and confounding severely limit their power to make causal inferences.

Chance — The probability[46] that an event will happen.

Coherence* — The extent to which a hypothesised causal association fits with pre-existing theory and knowledge (see *Modified Bradford Hill Guidelines*).

Cohort study* — The analytic epidemiological study in which subsets of a defined population can be identified who are, have been or, in the future may be, exposed or not exposed, or exposed in different degrees, to a factor or factors hypothesised to influence the occurrence of a given disease or other outcome. The main feature of cohort study is observation of large numbers over a long period (commonly years), with comparison of incidence rates in groups that differ in exposure levels; this study type may be retrospective or prospective.

Confidence interval (CI)* — The conventional form of an interval estimate, computed in statistical analyses, based on the theory of frequency probability. If the underlying statistical model is correct and there is no *bias*, a confidence interval derived from a valid analysis will, over unlimited

[46] The IEA *Dictionary of Epidemiology* (2008) states 'possibility' rather than 'probability'; however, for the purposes of the current report we prefer 'probability'.

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| | repetitions of the study, contain the true parameter with a frequency no less than its confidence level (often 95% is the stated level, but other levels are also used). |
| Confounder/plausible confounder | A factor (or plausible factor) that has an association with the exposure being investigated and an association with the outcome being measured within the data being used for the analysis. |
| Confounding* | Loosely, the distortion of a measure of the effect of an exposure on an outcome due to the association of the exposure with other factors (confounders) that influence the occurrence of the outcome. Confounding occurs when all or part of the apparent association between the exposure and the outcome is in fact accounted for by other variables that affect the outcome, and are not themselves affected by the exposure. |
| Cross-over study* | A method of comparing two (or more) treatments or interventions in which subjects, upon completion of one treatment, switch to the other; may be observational or experimental in design. |
| Cross-sectional study* | A study that examines the relationship between diseases (or other health-related characteristics) and other variables of interest as they exist in a defined population at one particular time. The presence or absence of disease, and the presence or absence of the other variables (or, if they are quantitative, their level), are determined in each member of the study population or in a representative sample at one particular time. The relationship between a variable and the disease can be examined (1) in terms of the prevalence of disease in different population subgroups defined according to the presence or absence (or level) of the variables, and (2) in terms of the presence or absence (or level) of the variables in the diseased versus the non-diseased. Note that disease prevalence rather than incidence is normally recorded in a cross-sectional study. The temporal sequence of cause and effect cannot necessarily be determined in a cross-sectional study. |
| Decibel (dB) | A unit of measure used to express the loudness of sound, calculated as the logarithmic ratio of sound pressure level against a reference pressure. |
| Direct evidence | Evidence directly or causally linking an exposure with a health outcome of interest through experimental evidence (randomised or non-randomised trial(s)) or observational evidence (see *Modified Bradford Hill Guidelines*). |
| Dose response* | An association between a given dose or set of doses (i.e. amount, duration, concentration) of an agent and the magnitude of a graded effect in an individual or a population; the relationship of observed outcomes (responses) in a population to varying levels of a protective or harmful agent such as a drug or an environmental contaminant. |

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|---|---|
| Economic benefit | A benefit to a person, business or society that can be expressed numerically as an amount of money that will be saved or generated as the result of an action. |
| Effect modifier* | A factor that modifies the measure of effect of a putative causal factor under study. There is effect modification when the selected effect measure for the factor under study varies across levels of another factor. An effect modifier may modify different measures in different directions and may modify one measure but not another; also known as a modifying factor. |
| Electromagnetic field (EMF) | A three-dimensional area in which *electromagnetic radiation* is present or active. |
| Electromagnetic radiation (EMR) | Radiation that is a combination of electric and magnetic radiation (such as X-rays, ultraviolet, infrared, visible light and radio waves); transmitted in a wave-like pattern as part of a continuous spectrum of radiation. |
| Epilepsy | A neurological disorder marked by sudden recurrent episodes of sensory disturbance, loss of consciousness and/or convulsions associated with abnormal electrical activity in the brain. |
| Epileptogenic | Causing an epileptic seizure. |
| Exposed population/group* | In epidemiology the exposed group (or, simply, the exposed) is often used to connote a group whose members have been exposed to a supposed cause of a disease or health state of interest, or who possess a characteristic that is a determinant of the health outcome of interest. |
| Exposure* | The process by which an agent comes into contact with a person or animal in such a way that the person or animal may develop the relevant outcome, such as a disease. For this review, exposure relates to being in the vicinity of *wind turbine* emissions. |
| Flicker | See '*Shadow flicker*'. |
| Flicker frequency | The rate of the light pulse or flash resulting from flicker; flash flicker greater than 3 Hz has the potential to provoke photosensitive seizures. |
| Flicker-induced seizure | Seizure provoked as a result of being exposed to flicker (usually at a frequency >3 Hz), e.g. *wind turbine* flicker or strobe lighting. |
| Frequency (hertz, Hz) | The number of sound waves or cycles passing a given point per second; measured in cycles per second (cps; 1 cps = 1 Hz). |
| Grey literature | Multiple document types and literature produced by government, academia, business and other organisations; may be produced in electronic and print formats; does not claim to be *peer reviewed* and is not controlled by commercial publishing (i.e. publishing is not the |

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| | primary activity of the producing body). |
| Health* | 1. The World Health Organization (WHO) described it, in 1948 in the preamble to its constitution, as: *A state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity.*<br><br>2. In 1984 a WHO health promotion initiative led to expansion of the original WHO description, which can be abbreviated to: *The extent to which an individual or a group is able to realise aspirations and satisfy needs, and to change or cope with the environment. Health is a resource for everyday life, not the objective of living; it is a positive concept, emphasising social and personal resources as well as physical capabilities.*<br><br>3. A state characterised by anatomical, physiological and psychological integrity; the ability to perform personally valued family, work and community roles; the ability to deal with physical, biological, psychological and social stress; a feeling of wellbeing; and freedom from the risk of disease and untimely death. |
| Health outcome | A measure of health or loss of health that can assess one or more of the following factors: mortality (i.e. rates of death or survival, years of potential life lost, *quality-adjusted life years* gained, *disability-adjusted life years* lost), morbidity (e.g. rates of disease or injury, infertility, disability, chronic pain, functional status, psychiatric disorders), positive measures of health (e.g. measures of wellbeing; physical, social or occupational function), or pregnancy and birth rates. |
| Ice throw | A hazard resulting from the build-up of ice on *wind turbine* rotor blade surfaces in cold climates; pieces or sheets of ice may be ‘thrown’ from spinning rotating blades once climatic conditions cause the ice to ‘shed’. |
| Inaudible sound | Sound that is below the *audibility threshold,* which is dependent on *sound pressure level* and *frequency*. |
| Infrasound | Sound in the <20 Hz frequency range. |
| Logistic regression | A type of *regression analysis* used for predicting the outcome of a categorical or binary dependent variable using one or several independent variables that are measured on continuous or categorical scales. |
| Low-frequency noise | Sound that falls within the frequency range of 20–200 Hz, although the upper limit can vary. |
| Masking* | Procedures intended to keep participants in a study from knowing some facts or observations that might bias or influence their actions or decisions regarding the study (syn: blinding). |

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| Mechanical sound | Sound produced from the movement and interaction of physical or mechanical parts; for *wind turbines*, sound produced by the interaction of electrical and rotational parts such as gear box and generator. |
| Mechanistic evidence (indirect evidence) | Evidence that a mechanism of action explains how the exposure in question may cause the health outcome of interest; the mechanism for causation may be biological, chemical or mechanical in nature (also see the *Modified Bradford Hill Guidelines*). |
| Mesopic vision | Mesopic light levels range from luminances (luminous intensity per unit area of light) of approximately 0.001 to 3 cd $m^{-2}$. Most night-time outdoor and traffic lighting scenarios are in the mesopic range. |
| Meta-analysis | A statistical approach to combine the results from multiple studies, with the aim of producing a more precise estimate of the impact of an intervention or exposure on a health (or other) outcome, given that the method increases statistical power. Individual studies contributing to the pooled result may be weighted according to certain criteria, which will vary depending on the meta-analytic method chosen. The analysis can also be used to determine patterns and differences in the impact of an intervention or exposure on a health outcome under different circumstances. |
| Moderator/mediator* | A variable that occurs in a causal pathway from a causal (independent) variable to an outcome (dependent) variable. It causes variation in the outcome variable and itself is caused to vary by the original causal variable. Such a variable will be associated with both the causal and the outcome variables. Also known as an intermediate, intervening or contingent variable. |
| Modified Bradford Hill Guidelines | A set of guidelines proposed to determine whether there is a causal relationship between an exposure and an outcome in the absence of experimental evidence, revised from those originally devised by the epidemiologist and statistician Austin Bradford Hill; the Guidelines fall into categories of *direct, mechanistic* and *parallel evidence* (see Table 5 for the causality framework for this review). |
| Morbidity* | 1. Any departure, subjective or objective, from a state of physiological or psychological wellbeing. In this sense sickness, illness and morbid condition are similarly defined and synonymous.<br><br>2. The WHO Expert Committee on Health Statistics noted in its sixth report (1959) that morbidity could be measured in terms of three units:<br>a. persons who were ill<br>b. the illnesses (periods or spells of illness) that these persons experienced<br>c. the duration (days, weeks etc.) of these illnesses. |

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| Mortality | Death |
| Nocebo effect | An unpleasant or adverse effect attributable to administration of or exposure to a *placebo*; in this case the placebo may be referred to as a nocebo. |
| Noise | Unwanted sound or an unwanted combination of sounds. |
| Narrative review | A literature review conducted without a pre-defined protocol or method, including an exhaustive search of the literature, pre-specified criteria for selecting studies and pre-defined approaches to critical appraisal of the internal and external validity of the results obtained. A narrative review is not considered to be transparent, unbiased and reproducible by an independent reviewer. |
| Odds ratio (OR)* | The ratio of two odds, i.e. the ratio of the odds (*probability/1-probability*) of an event occurring in one group to the odds of it occurring in another group. The term 'odds' is defined differently according to the situation under discussion. Consider the following notation for the distribution of a binary exposure and a disease in a population or sample:<br>Exposed / Unexposed<br>Disease: a, b<br>No disease: c, d<br>The odds ratio (cross-product ratio) is ad/bc. |
| Parallel evidence (indirect evidence) | Evidence obtained from related fields that support the association between the exposure of interest and an adverse health effect; evidence may occur in a setting other than that under investigation, and should have replicable results under the same conditions or with similar results under different conditions (also see *Modified Bradford Hill Guidelines*). |
| Participants/responders | Those who have participated in a trial or study, or have responded to a survey questionnaire or interview. |
| Pearling | The process of checking the reference lists of articles included in a systematic review for more articles that are potentially relevant. |
| Pearson's correlation coefficient (r) | A coefficient derived with Pearson's product-moment correlation; the values range from -1.0 to 1.0, with a high value indicating a strong correlation between variables. |
| Peer-reviewed literature | Published literature that has undergone evaluation by other people in the same field in order to maintain or enhance the quality of the work or performance in that field; in this review, databases included in the *black literature* search contain only peer-reviewed literature. |
| Photoparoxysmal response | A physiological reaction to intermittent photic stimulation or other visual stimuli of daily life; detected and measured with electroencephalography (EEG). |

Photopic vision — Daylight vision; normal vision in daylight; vision with sufficient illumination that the cones are active and hue can be perceived.

Photosensitivity — An abnormal sensitivity to light stimuli, usually detected with electroencephalography (EEG) as a paroxysmal reaction to intermittent photic stimulation.

Photosensitive epilepsy — A form of epilepsy in which seizures are triggered by visual stimuli that form patterns in time or space, such as flashing lights; bold, regular patterns; flicker; or regular moving patterns.

Physical emission — For *wind turbines*, recognised physical emissions include *noise*, *infrasound and low-frequency noise*, *shadow flicker* and *electromagnetic radiation*.

Placebo* — A medication or procedure that is inert (i.e. one having no pharmacological effect) but intended to give patients the perception that they are receiving treatment or assistance for their complaint; from the Latin *placebo*, 'I shall please'.

Prevalence* — A measure of disease occurrence; the total number of individuals who have an attribute or disease at a particular time (it may be a particular period) divided by the population at risk of having the attribute or disease at that time or midway through the period; when used without qualification, the term usually refers to the situation at a specified point in time (point prevalence); a measure of occurrence or disease frequency, often used to refer to the proportion (not the rate) of individuals in a population who have a disease or condition.

Probability (p)* — A measure, ranging from 0 to 1, of the degree of belief in a hypothesis or statement. All probabilities obey the laws given by the axioms that:

a. All probabilities (p) are 0 or greater: for any event or statement A, $p(A) \geq 0$
b. The probability of anything certain to happen is 1; i.e. if A is certain, $p(A)=1$
c. If two events or statements, A and B, cannot both be true at once (i.e. they are mutually exclusive), the probability of their conjunction (A or B) is the sum of their separate probabilities: $p(A \text{ or } B)=p(A)+p(B)$.

*P* (or p) value* — The probability that a test statistic would be as extreme as observed, or more extreme, if the null hypothesis was true; the letter *P* (or p) stands for this probability. It is usually close to the probability that the difference observed or greater could have occurred by chance alone, i.e. under the null hypothesis. Investigators may arbitrarily set their own significance levels, but in most biomedical and epidemiological work, a study result whose *P* (or p) value is less than 5% ($p<0.05$) or 1% ($p<0.01$) is considered sufficiently unlikely to have occurred by chance to justify the designation 'statistically significant'.

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| Pseudo-$R^2$ | The proportion of the total variability in outcome that is accounted for by the model parameter(s), calculated using various methods; used in *logistic regression* as an approximation of the $R^2$ (coefficient of determination) calculated in linear regression—the more variability explained, the better the prediction model. |
| Publication bias* | 1. The result of the tendency of authors to submit, organisations to encourage, reviewers to approve, and editors to publish articles containing "positive" findings (e.g., a gene–disease association), especially "new" results, in contrast to findings or reports that do not report statistically significant or "positive" results.<br><br>2. Tendency of authors to preferentially include in their study reports findings that conform to their preconceived notions or outcomes preferred by their institution or sponsor. |
| Quality of life (QoL) | An individual's perception of their position in life in the context of the culture and value systems in which they live, and in relation to their goals, expectations, standards and concerns. It is a broad-ranging concept affected in a complex way by the person's physical health, psychological state, level of independence and social relationships, and their relationship to salient features of their environment. |
| Randomisation | A system of allocating individuals to groups with a known (usually equal) chance of being assigned to particular groups. The approach is similar to tossing a coin (e.g. assignment to one group if the coin lands 'heads' and to another group if the coin lands 'tails'); it is often computer generated by an independent third party as this helps avoid *bias*; i.e., it reduces intentional or unintentional subverting of randomisation by concealing the allocation. |
| Randomised controlled trial (RCT)* | An epidemiological experiment in which subjects in a population are randomly allocated into groups, usually called study and control groups, to receive or not receive an experimental preventive or therapeutic procedure, manoeuvre or intervention. The results are assessed by rigorous comparison of rates of disease, death, recovery or other appropriate outcome in the study and control groups. RCTs are generally regarded as the most scientifically rigorous method of hypothesis testing available in epidemiology and medicine. Nonetheless, they may suffer serious lack of generalisability due, for example, to the non-representativeness of patients who are ethically and practically eligible, chosen or consent to participate. |
| Recall bias* | Systematic error due to differences in accuracy or completeness of recall to memory of past events or experiences. For example, a mother whose child has died of leukemia may be more likely than the mother of a healthy living child to remember details of such past experiences as use of x-ray services when the child was *in utero*. |
| Regression analysis | A statistical technique for estimating the 'best' mathematical model to describe or predict the dependent variable as a function of the |

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| | independent variable(s). There are several regression models that suit different needs, common forms being linear, logistic and proportional hazards. |
| Relative risk* | The ratio of the risk of an event among the exposed to the risk among the unexposed; this usage is synonymous with risk ratio. |
| Replication*/replicability | The execution of an experiment or survey more than once so as to confirm the findings, increase precision and obtain a closer estimation of sampling error. |
| Reversibility | The ability of an effect of an intervention or exposure to be reversed by its removal. |
| Risk factor* | 1. An aspect of personal behaviour or lifestyle, an environmental exposure, or an inborn or inherited characteristic that, on the basis of scientific evidence, is known to be associated with meaningful health-related condition(s).<br><br>2. An attribute or exposure that is associated with an increased probability of a specified outcome, such as the occurrence of a disease. Not necessarily a causal factor, it may be a risk marker.<br><br>3. A determinant that can be modified by intervention, thereby reducing the probability of occurrence of disease or other outcomes. It may be referred to as a modifiable risk factor, and logically must be a cause of the disease. |
| Sample selection bias* (sampling bias, see selection bias) | Systematic error due to the methods or procedures used to sample or select the study subjects, specimens, or items (e.g., scientific papers), including errors due to the study of a nonrandom sample of a population. |
| Selection bias* | 1. Bias of the estimated effect of an exposure on an outcome due to conditioning on a common effect of the exposure and the outcome (or of causes of the exposure and the outcome).<br><br>2. Distortions that result from procedures used to select subjects and from factors that influence participation in the study. A distortion in the estimate of the effect due to the manner in which subjects are selected for the study. Systematic differences in past exposures and other characteristics between subjects who take part in a study and those who do not may or may not cause selection biases, depending on the study limited to volunteers or to persons present in a particular place at a particular time; studies based on disease survivors; hospital-based studies that cannot include patients who die before hospital admission due to acute illness or that do not include persons with mild conditions, which seldom require hospital care; case-control studies in which selection of cases and controls is differentially influenced by cost, distance, concomitant illnesses, access to diagnostic procedures, or other factors. Selection biases may be |

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| | related to confounding and information biases. In clinical trials, two kinds of selection bias are especially relevant: sample selection bias or sampling bias (systematic differences among participants and nonparticipants in trials) and attrition bias (systematic differences due to selective loss of subjects, also known as follow-up bias).<br><br>Selection bias can virtually never be corrected by statistical analysis. It is a common and commonly overlooked problem, not just in epidemiological studies but also in clinical and basic biological studies. |
| Scotopic vision | The vision of the eye under low light conditions. |
| Shadow flicker | The flickering effect caused when rotating *wind turbine* blades intermittently cast shadows over neighbouring properties, through constrained openings such as windows, as they turn; *exposure* is determined by the hub height, blade diameter, height of the sun and blade direction relative to the observer, as well as by environmental factors such as time of day, weather conditions, wind direction, wind speed and geographical location. |
| Similarity | A description of studies having findings that differ little from each other. |
| Snowballing | A process of locating, tracking and chasing down references in the footnotes and bibliographies of articles and other documents as part of a continuous process of scanning and collating references. |
| Socioeconomic status* | A descriptive term for a person's position in society, which may be expressed on an ordinal scale using such criteria as income, level of education attained, occupation, value of dwelling place etc. |
| Sound | An energy form that travels from a source in the form of waves or pressure fluctuations, transmitted through a medium and received by a receiver (e.g. human ear). |
| Sound frequency ranges | Infrasound <20 Hz, low-frequency sound 20–200 Hz, mid-frequency sound 200–2000 Hz, high-frequency sound 2000–20,000 Hz. |
| Sound intensity (I) | A measure of the *sound power* per unit area of a sound wave; alternatively, the product of the sound pressure and the particle velocity. |
| Sound power | A measure of the sonic energy per unit of time of a sound wave; alternatively called acoustic power; calculated by the sound intensity times the unit area of the wave; the total acoustic power emitted in all directions by the source. |
| Sound pressure | A measure of the *sound power* at a given observer location; can be measured at that specific point by a single microphone or receiver. |
| Sound pressure level | A logarithmic measure of the *sound pressure* of a sound relative to a reference value, measured in decibels (dB) above a standard |

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| (SPL) | reference level using the formula SPL = $10\log_{10}[p^2/p_{ref}^2]$, where $p_{ref}$ is the reference pressure or 'zero' reference for airborne sound ($20\times10^{-6}$ pascals). |
| Spatial proximity | A description of evidence that shows that a health outcome occurs at the same site as the exposure under investigation (see *Modified Bradford Hill Guidelines*). |
| Spearman's correlation coefficient ($r_s$) | A coefficient derived with Spearman's rank-order correlation; the values range from -1.0 to 1.0, with a high value indicating a strong correlation between variables. |
| Statistical significance* | 1. The probability of the observed or larger value of a test statistic under the null hypothesis; often equivalent to the probability of the observed or larger degree of association under the null hypothesis. This usage is synonymous with P (or *p*) *value*.<br>2. A statistical property of an observation or estimate that is unlikely to have occurred by chance alone. |
| Stress (distress) | A state of mental or emotional strain or tension resulting from adverse or demanding circumstances; distress is a state of extreme anxiety, sorrow or pain. |
| Systematic literature review | A process by which a body of literature is reviewed and assessed using systematic pre-specified methods that are intended to identify, appraise, select and synthesise high-quality evidence; the methodology is designed to reduce *bias* in the review process and for findings to be reproducible. |
| Unspecified noise | Noise for which study authors have not specified a frequency range or decibel level. |
| Urbanisation | The physical growth of urban areas as a result of rural migration and suburban concentration into cities. |
| Temporal proximity | A description of evidence that shows that an exposure precedes an effect or health outcome (see *Modified Bradford Hill Guidelines*). |
| Tinnitus | The conscious perception of sound in the absence of an external source. |
| Tonal sound | Sound at discrete frequencies. |
| Weighted sound pressure level | The results of measuring a sound and applying a filter:<br>A-weighting: the most common scale for assessing environmental and occupational sound. The result is a level measured in dB(A).<br>C-weighting: a filter that does not reduce low frequencies to the same extent as the A-weight filter. The result is a level measured in dB(C). |

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| | G-weighting: designed for infrasound. The result is a level measured in dB(G). |
| Wind farm | A collection of *wind turbines*, usually defined by geographical location. |
| Wind power | The conversion of wind energy into a useful form of energy, e.g. using *wind turbines* to make electrical power, windmills for mechanical power, or wind-powered pumps. |
| Wind turbine | A device that converts kinetic energy from the wind, also described as converting wind energy into mechanical energy; if the mechanical energy is used to produce electricity, the device may be called a wind turbine or wind power plant. |
| Wind turbine emissions | Forces emanating from *wind turbines* that have the potential to affect those in the vicinity, i.e. *audible sound*, *infrasound*, *electromagnetic radiation* and *shadow flicker*. |

# Abbreviations

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| 95%CI | Confidence interval of 95%; a range of values within which there is a 95% probability of the true value occurring |
| ALS | Amyotrophic lateral sclerosis (a form of motor neuron disease) |
| ANOVA | Analysis of variance |
| β | Beta coefficient for a variable in multiple linear regression; scale dependent |
| CNS | Central nervous system |
| dB(A) | A-weighted sound pressure level (decibels) |
| dB(C) | C-weighted sound pressure level (decibels) |
| dB(G) | G-weighted sound pressure level (decibels) |
| dB(lin) | Unweighted sound pressure level (decibels), also known as linear or flat-weighting and now superseded by Z-weighting |
| EEG | Electroencephalography; a recording of electrical activity along the scalp by measurement of voltage fluctuations within the neurons of the brain |
| EMF | Electromagnetic field; can include ELF—low-frequency electromagnetic field, IF—intermediate frequency field, RF—radiofrequency field |
| EMR | Electromagnetic radiation |
| EPA | Environment Protection Authority (South Australia) |
| EPHC | The Environment Protection and Heritage Council of Australia |
| ESS | Epworth Sleepiness Scale |
| Exp(b) | The exponential function of the coefficients of the independent variables in a logistic regression, which corresponds to the odds ratio |
| GHQ | General Health Questionnaire |
| HRQOL | Health-Related Quality of Life questionnaire |
| Hz | Hertz; a measure of frequency equivalent to one cycle per second |
| ILFN | Infrasound and low-frequency noise |
| $L_{eq}$ (also $LA_{eq}$) | When a noise varies over time, the $L_{eq}$ is the equivalent continuous sound that would contain the same sound energy as the time-varying sound (e.g. $L_{eq}$ = 60 dB). It is common practice to measure noise levels using the A-weighting setting built into all sound-level meters, in which case the term is properly known as $LA_{eq}$ (e.g. $LA_{eq}$ = 60 dB or $L_{eq}$ = 60 dB(A)) |
| $L_{max}$ | The maximum sound power level measured over a specified period |
| µg | Microgram, equivalent to $10^{-6}$ grams; a measure of weight |
| µT | Microtesla; a measure of electromagnetic radiation, 1 µT = 10 mG |
| mG | Milligauss, 10 mG = 1 µT (microtesla); a measure of electromagnetic radiation |
| n | Number of respondents or participants |
| NHMRC | National Health and Medical Research Council |

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| OR | Odds ratio |
| pmol/L | Picomoles per litre, equivalent to $10^{-12}$ mol/L; a chemical measure of concentration |
| nmol/L | Nanomoles per litre, equivalent to 1000 pmol/L |
| p | Probability |
| PPR | Photoparoxysmal response |
| PRISMA | Preferred Reporting Items for Systematic reviews and Meta-analysis |
| PSQI | Pittsburgh Sleep Quality Index |
| QoL | Quality of life |
| r | Pearson’s correlation coefficient |
| REM sleep | Rapid eye movement sleep |
| $r_s$ | Spearman’s correlation coefficient |
| SES | Socioeconomic status |
| SF-36v2 | Short Form (36) Health Survey (version 2)—provides a summary Physical Component Score (PCS) and a summary Mental Component Score (MCS) |
| SPL | Sound pressure level |
| SWA | Slow wave activity |
| SWS | Slow wave sleep |
| $X_{shadow, max}$ | The maximum distance from a *wind turbine* that *shadow flicker* can extend, which can be estimated by the formula: $X_{shadow, max} = (H+R-h_{view})/\tan(\alpha_s)$ where $H$ = turbine height, $R$ = rotor radius, $h_{view}$ = height of the viewing point, $\alpha_s$ = altitude of the sun (Ellenbogen et al. 2012) |

# APPENDIX A – SEARCH STRATEGIES

*Grey literature sources*

Wind turbine*; wind farm*; wind power; wind turbine syndrome
Limits: 1981 – 10/2012; English language; human studies

| Source | Location | Search terms |
|---|---|---|
| Google Scholar | http://scholar.google.com.au/ | Health AND human AND ("wind farm" OR "wind tower" OR "wind turbine" OR "wind power" OR "wind technology" OR "wind energy")<br>Limits: the first 200 citations will be assessed |
| PapersFirst database (database of papers presented at conferences) | University Library ('databases' search) | (health) AND ("wind turbin*" OR "wind tower*" OR "wind farm*" OR "wind power*" OR "wind renewable energy" OR "wind power plant*" OR "wind technolog*" OR "wind energy" OR "wind resourc*")<br>Limits: English language, published 1981 - 2012 |
| ProceedingsFirst database (database of conference proceedings) | University Library ('databases' search) | (health) AND ("wind turbin*" OR "wind tower*" OR "wind farm*" OR "wind power*" OR "wind renewable energy" OR "wind power plant*" OR "wind technolog*" OR "wind energy" OR "wind resourc*")<br>Limits: English language, published 2011 - 2012 |
| EPPI Centre (papers on public policy)<br>Evidence library<br>Bibliomap database<br>DoPHER database<br>TroPHI database | http://eppi.ioe.ac.uk/cms/ | "wind" (free text search) |
| Scirus (documents from science/scientist webpages)<br>Restricted to 'Other web' sources to avoid duplicating black literature sources | http://www.scirus.com/ | Wind turbine*" OR "wind farm*" OR "wind power" OR "renewable energy" OR "power plant*" OR "wind turbine syndrome" OR "energy generating resources" OR "wind tower*" OR "wind |

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| | | energy" OR "wind technology" AND "health" AND "health effects" AND "adverse health effects" AND "adverse health effects" AND "human*" |
| WHOLIS (World Health Organization technical documents) | http://www.who.int/library/databases/en/ | 'wind' (words or phrase search) |
| TROVE (National Library of Australia resources) | http://trove.nla.gov.au/ | "wind farm"<br>"wind power"<br>"wind tower"<br>"wind turbine"<br>"wind technology"<br>"wind energy"<br>"wind" AND "renewable energy"<br>"wind resources" |
| WorldCat (network of library content) | http://www.worldcat.org/ | ("wind turbine" OR "wind tower" OR "wind farm" OR "wind power" OR "wind renewable energy" OR "wind power plant" OR "wind technology" OR "wind energy" OR "wind resource") AND (noise OR flicker OR "electromagnetic radiation" OR health)<br>Limits: key word search, English, 1981 – 2012, articles |
| OpenDOAR (directory of open access repositories) | http://www.opendoar.org/search.php | ("wind farms" OR "wind turbines" OR "wind towers" OR "wind power") AND human AND (health OR flicker OR noise OR electromagnetic)<br>The first 50 citations will be assessed |
| MedNar<br>Restricted to World Health Organization, US Department of Health and Human Services, National Center for Health Statistics | www.mednar.com | Keyword: ("wind farms" OR "wind turbines" OR "wind towers" OR "wind power") AND (health OR flicker OR human OR noise OR electromagnetic) |

# APPENDIX B – EVIDENCE TABLES FOR INCLUDED ARTICLES

*Evidence map—11 articles relating to 7 studies*

| Study identifier | Most comprehensive report | Study location | Articles contributing additional data on the study and/or providing additional analyses or comparisons between studies |
|---|---|---|---|
| NL-07 | Bakker et al. (2012) | The Netherlands | Van den Berg et al. (2008)<br>Pedersen et al. (2009)<br>Pedersen (2011) |
| Krogh et al. (2011) | Krogh et al. (2011) | Ontario, Canada | |
| Morris (2012) | Morris (2012) | South Australia | |
| Nissenbaum, Aramini and Hanning (2012) | Nissenbaum, Aramini and Hanning (2012) | Maine, USA | |
| SWE-00 | Pedersen and Persson Waye (2004) | Sweden | Pedersen and Larsman (2008)<br>Pedersen (2011) |
| SWE-05 | Pedersen and Persson Waye (2007) | Sweden | Pedersen and Larsman (2008)<br>Pedersen (2011) |
| Shepherd et al. (2011) | Shepherd et al. (2011) | New Zealand | |

## *Included articles – citation details*

Bakker, RH, Pedersen, E, van den Berg, GP, Stewart, RE, Lok, W & Bouma, J 2012, 'Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress', *Science of the Total Environment*, vol. 425, pp. 42–51.

Krogh, CME, Gillis, L, Kouwen, N & Aramini, J 2011, 'WindVOiCe, a self-reporting survey: adverse health effects, industrial wind turbines, and the need for vigilance monitoring', *Bulletin of Science, Technology & Society*, vol. 31, no. 4, pp. 334–345.

Morris, M 2012, 'Waterloo wind farm survey', Electronic self-published report, Accessed 18 January 2013, <www.wind-watch.org/news/wp-content/uploads/2012/07/Waterloo-Wind-Farm-Survey-April-2012-Select-Committee.pdf>.

Nissenbaum M, Aramini J & Hanning C 2012, 'Effects of industrial wind turbine noise on sleep and health', *Noise & Health*, vol. 14, no. 60, pp. 237–243.

Pedersen, E 2011, 'Health aspects associated with wind turbine noise: results from three field studies', *Noise Control Engineering Journal*, vol. 59, no. 1, pp. 47–53.

Pedersen, E & Larsman, P 2008, 'The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines', *Journal of Environmental Psychology*, vol. 28, no. 4, pp. 379–389.

Pedersen, E & Persson Waye, K 2004, 'Perception and annoyance due to wind turbine noise: a dose-response relationship', *Journal of the Acoustical Society of America*, vol. 116, no. 6, pp. 3460–3470.

Pedersen, E & Persson Waye, K 2007, 'Wind turbine noise, annoyance and self-reported health and well-being in different living environments', *Occupational and Environmental Medicine*, vol. 64, no. 7, pp. 480486.

Pedersen, E, van den Berg, F, Bakker, R & Bouma, J 2009, 'Response to noise from modern wind farms in The Netherlands', *Journal of the Acoustical Society of America*, vol. 126, p. 634.

Shepherd, D, McBride, D, Welch, D, Dirks, KN & Hill, EM 2011, 'Evaluating the impact of wind turbine noise on health-related quality of life', *Noise & Health*, vol. 13, no. 54, pp. 333–339.

Van den Berg, G, Pedersen, E, Bouma, J & Bakker, R 2008, *Project WINDFARM perception: Visual and acoustic impact of wind turbine farms on residents*, 2012/11/13/06:24:13, University of Groningen, FP6-2005-Science-and-Society-20, Specific Support Action, Project no. 044628, viewed 13 November 2012, <http://www.epaw.org/documents/WFp-final-summary-1.pdf>.

## Study NL-07

<table>
<tr><td colspan="3">ARTICLE DETAILS</td></tr>
<tr><td colspan="3">Reference [1]<br>Bakker, RH, Pedersen, E, van den Berg, GP, Stewart, RE, Lok, W & Bouma, J 2012, 'Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress', Science of the Total Environment, vol. 425, pp. 42–51.</td></tr>
<tr><td colspan="3">Affiliation/source of funds [2]<br>Department of Applied Research in Care, University Medical Center Groningen, University of Groningen, The Netherlands; Halmstad University and Environmental Psychology, Department of Architecture and Built Environment, Lund University, Halmstad, Sweden; GGD Amsterdam Public Health Service, Amsterdam, The Netherlands; Department of Community and Occupational Health, University Medical Center Groningen, University of Groningen, The Netherlands; Department of Health Care, Science shop, University Medical Center Groningen, University of Groningen, The Netherlands.<br><br>No external funding for the study was declared; however, this study is a selected analysis of an earlier publication detailing research funded by the European Union.</td></tr>
<tr><td>Study design [3]<br>Cross-sectional study—see van den Berg, G, Pedersen, E, Bouma, J & Bakker, R 2008, Project WINDFARM perception: visual and acoustic impact of wind turbine farms on residents, University of Groningen, FP6-2005-Science-and-Society-20, Specific Support Action, Project no. 044628.</td><td>Level of evidence [4]<br>IV</td><td>Location/setting [5]<br>Rural and urban settings in The Netherlands with flat topography; rural environments were classified according to whether or not a major road was located within 500 m of the closest wind turbine.<br><br>Proximity/distance:<br>Study population sampled from addresses within 2.5 km of a wind turbine, with a second turbine <500 m from the first turbine.</td></tr>
<tr><td>Exposure description [6]<br>Wind farm details:<br>Two or more turbines within 2.5 km of any given residence surveyed; the two closest turbines were required to have nominal electric power ≥500 kW. Additional turbines within 2.5 km of residence were included in analysis regardless of power output.<br><br>Specific exposure details:<br>Modelled sound pressure in A-weighted decibels (dB(A))[a] outside residences averaged over time with 8 m/s downwind; range = 21–54 dB(A), mean = 35 dB(A).</td><td colspan="2">Control(s) description [8]<br>No non-exposed groups were included in the study. Study population was divided into categories of estimated SPL (see ‘Specific exposure details’ and ‘Population characteristics’).<br><br>Sample size [9]<br>See ‘Population characteristics’.<br><br>Survey sample selected from addresses provided by Land Registry Office – for each subgroup either a random sample was selected or all addresses that</td></tr>
</table>

Frequency range of sound not reported, i.e. exposure profile in terms of audible noise versus infrasound not analysed.

[a] Sound power levels collected from reports by consultancies, manufacturers and local authorities; or, where data were unavailable (older/smaller machines), the sound power level of a turbine with the same dimensions and electrical output was used; propagation of sound from turbines was calculated in accordance with the ISO standard model (see ISO 1996, 'Attenuation of sound during propagation outdoors. Part 2: General method of calculation', ISO 9613-2, International Organization for Standardization, Geneva).

**Sample size [7]**

Total, n=1948; respondents, n=725; non-respondents, n=1223; response rate 37%.

matched postcodes within 2.5 km of selected wind turbines. Subgroups were: rural area, rural area with a major road, densely populated built-up area.

**Population characteristics [10]**

As per van den Berg et al. (2008) and Bakker et al. (2012).

| | Sound pressure level, in dB(A) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | <30 | | 30–35 | | 36–40 | | 41–45 | | >45 | | Total | |
| Study sample, n | 491 | | 589 | | 421 | | 250 | | 197 | | 1948 | |
| Respondents, n (%) | | | | | | | | | | | | |
| Built-up area | 68 | (37) | 84 | (38) | 28 | (17) | 18 | (19) | 1 | (2) | 199 | (23) |
| Rural with main road | 50 | (27) | 70 | (32) | 59 | (38) | 36 | (38) | 30 | (46) | 245 | (36) |
| Rural without main road | 67 | (36) | 65 | (30) | 75 | (47) | 40 | (43) | 34 | (52) | 281 | (41) |
| Total | 185 | (38) | 219 | (37) | 162 | (38) | 94 | (38) | 65 | (33) | 725 | (100) |
| Age, mean (years) | NR | | NR | | NR | | NR | | NR | | 51 | |
| Sex, % male | NR | | NR | | NR | | NR | | NR | | 51 | |

**Length of follow-up [11]**

NA (cross-sectional study design).

**Outcome(s) measured and/or analyses undertaken [12]**

Author-developed survey measuring response (sleep disturbance, psychological stress, annoyance) to wind turbine sound outdoors and indoors, overall, and those who did and did not benefit economically from wind turbines.

Correlations between sound exposure and:

- sleep disturbance
- psychological distress scores as determined by General Health Questionnaire (GHQ-12) *[validated]*
- annoyance outside
- annoyance inside.

Correlations between variables were considered across

| | |
|---|---|
| | different environments in terms of background noise ('noisy' and 'quiet') and across different response groups ('do notice wind turbine noise' and 'do not notice wind turbine noise'). |
| **INTERNAL VALIDITY**<br><br>**Confounding subscale [13]**<br><br>***Comment on sources of confounding:***<br>Few details on characteristics of participants were reported. Adjustments made for influence of age, gender, employment, terrain, urbanisation, economic benefit from turbines, background noise, noise sensitivity, attitude to turbines and turbine visibility. Findings may be partly explained by differences in levels of background sound between rural and urban areas. Covariates varied between the analyses. Plausible confounders that were not addressed included socioeconomic factors, chronic disease and risk factors for chronic disease and occupation.<br><br>**Bias subscale [14]**<br><br>***Comment on sources of bias:***<br>High potential for sample selection bias due to low response rate. It is uncertain whether participants were effectively masked regarding the purpose of the survey (and thus the impact of recall bias is uncertain) – questions about other environmental factors were added to obtain better masking of the main topic. Equal weight was given to questions regarding other environmental factors but it is unclear whether study intent was known, leading to the possibility of responder bias (conscious or unconscious). Non-responder analysis conducted but only on 95 of the 200 randomly selected non-responders (non-responders=1223), so it is may not be representative. | **EXTERNAL VALIDITY**<br><br>**Generalisability [15]**<br><br>Survey mailed to a sample of households within 2.5 km of wind turbines; potential for differences between the total population living near the included wind farms and those that responded to the questionnaire.<br><br>**Applicability [16]**<br><br>Unknown whether the population characteristics and the wind turbine exposures of those living near wind farms in The Netherlands are comparable to those living near wind farms in Australia. |
| **Reporting subscale [17]**<br><br>***Comment on quality of reporting:***<br>Main deficits include lack of reporting on distribution of participant characteristics across the nominated and estimated sound exposure levels (only an overall measure for mean age and sex) and limited demographic information on non-responders. | |
| **Chance [18]**<br><br>This paper by Bakker et al. presents additional analyses of earlier work, led by van den Berg (see below). Bakker et al. present numerous statistical tests for correlations based on structural equation modelling. No adjustments | |

were made for multiple comparisons. The possibility of spurious significant associations arising by chance cannot be excluded.

**Overall quality assessment (descriptive) [19]**

On the basis of the Internal Validity assessment made above, and the detailed critical appraisal of the study given in Table 7, this study is considered poor quality for the purpose of this review.

There was some adjustment for potential confounding, although some plausible confounders were not addressed. There is potential for recall bias and outcome misclassification due, respectively, to uncertainty in the effectiveness of masked study intent and dependence on self-report in a questionnaire that has not been formally validated. There is a high risk of exposure misclassification (time and person criteria not well-defined), sample selection bias (37% response rate) and statistically significant associations occurring due to chance (multiple statistical tests and no correction for multiple comparisons).

## RESULTS

**Adverse effect outcomes [20]**

*Response to wind turbine sound, outdoors and indoors*

| | Do not notice, n (%) | Notice, not annoyed, n (%) | Slightly annoyed, n (%) | Rather annoyed, n (%) | Very annoyed, n (%) | Total, n (%) |
|---|---|---|---|---|---|---|
| Sound outdoors | 284 (40) | 259 (37) | 92 (13) | 44 (6) | 29 (4) | 708 (100) |
| Sound indoors | 465 (67) | 139 (20) | 54 (8) | 21 (3) | 20 (3) | 699 (100) |

*Response to outdoor wind turbine among economically benefiting and non-benefiting respondents*

| | Do not notice, n (%) | Notice, not annoyed, n (%) | Slightly annoyed, n (%) | Rather annoyed, n (%) | Very annoyed, n (%) | Total, n (%) |
|---|---|---|---|---|---|---|
| Benefit | 255 (44) | 184 (31) | 78 (13) | 41 (7) | 28 (5) | 586 (100) |
| No benefit | 15 (15) | 68 (69) | 13 (13) | 2 (2) | 1 (1) | 99 (100) |

*Response to indoor wind turbine among economically benefiting and non-benefiting respondents*

| | Do not notice, n (%) | Notice, not annoyed, n (%) | Slightly annoyed, n (%) | Rather annoyed, n (%) | Very annoyed, n (%) | Total, n (%) |
|---|---|---|---|---|---|---|
| Benefit | 394 (68) | 98 (17) | 46 (8) | 21 (4) | 20 (4) | 579 (100) |
| No benefit | 53 (54) | 39 (39) | 7 (7) | 0 (0) | 0 (0) | 99 (100) |

*Response to wind turbine sound outdoors in relation to 5-dB(A) intervals of sound (respondents with economic benefit only)*

| | <30 n (%) | 30–35 n (%) | 36–40 n (%) | 41–45 n (%) | >45 n (%) | Total n (%) |
|---|---|---|---|---|---|---|
| Do not notice | 124 (75) | 92 (46) | 30 (21) | 7 (12) | 2 (10) | 255 (44) |
| Notice, not annoyed | 34 (21) | 71 (36) | 52 (37) | 22 (37) | 5 (24) | 184 (31) |
| Slightly annoyed | 4 (2) | 20 (10) | 30 (21) | 16 (27) | 8 (38) | 78 (13) |
| Rather annoyed | 2 (1) | 13 (7) | 19 (14) | 4 (7) | 3 (14) | 41 (7) |
| Very annoyed | 2 (1) | 3 (2) | 9 (6) | 11 (18) | 3 (14) | 28 (5) |
| Total | 166 (100) | 199 (100) | 140 (100) | 60 (100) | 21 (100) | 586 (100) |

*Response to wind turbine sound indoors in relation to 5-dB(A) intervals of sound (respondents without economic benefit only)*

| | <30 n (%) | 30–35 n (%) | 36–40 n (%) | 41–45 n (%) | >45 n (%) | Total n (%) |
|---|---|---|---|---|---|---|
| Do not notice | 144 (86) | 140 (73) | 85 (61) | 18 (30) | 7 (33) | 394 (68) |
| Notice, not annoyed | 19 (11) | 27 (14) | 29 (21) | 15 (25) | 8 (38) | 98 (17) |
| Slightly annoyed | 2 (1) | 16 (8) | 14 (10) | 12 (20) | 2 (10) | 46 (18) |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rather annoyed | 0 | (0) | 6 | (3) | 6 | (4) | 6 | (10) | 3 | (14) | 21 | (4) |
| Very annoyed | 2 | (1) | 2 | (1) | 6 | (4) | 9 | (15) | 1 | (5) | 20 | (4) |
| Total | 167 | (100) | 191 | (100) | 140 | (100) | 60 | (100) | 21 | (100) | 579 | (100) |

*Sound sources of sleep disturbance in rural and urban area types*

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

*Correlation matrices*

| | Sleep disturbance | Psychological distress | Age |
|---|---|---|---|
| Quiet + noisy, do not notice turbine sound (n=323) | | | |
| Sleep disturbance | NA | NR | NR |
| Psychological distress | 0.191** | NA | NR |
| Age | 0.172** | –0.129* | NA |
| Sound exposure | 0.005 | 0.053 | –0.068 |

| | Annoyance outside | Annoyance inside | Sleep disturbance | Psychological distress | Age |
|---|---|---|---|---|---|
| Quiet + noisy, do not notice turbine sound (n=323) | | | | | |
| Annoyance outside | NA | NR | NR | NR | NR |
| Annoyance inside | 0.78[a] | NA | NR | NR | NR |
| Sleep disturbance | 0.444[a] | 0.493[a] | NA | NR | NR |
| Psychological distress | 0.184[a] | 0.243[a] | 0.205[a] | NA | NR |
| Age | 0.116 | 0.084 | 0.071 | –0.77 | NA |
| Sound exposure | 0.281[a] | 0.206[a] | 0.094 | 0.160[a] | –0.084 |

| | Annoyance outside | Annoyance inside | Sleep disturbance | Psychological distress | Age |
|---|---|---|---|---|---|
| Noisy, do notice turbine sound (n=147) | | | | | |
| Annoyance outside | NA | NR | NR | NR | NR |
| Annoyance inside | 0.782[a] | NA | NR | NR | NR |
| Sleep disturbance | 0.499[a] | 0.534[a] | NA | NR | NR |
| Psychological distress | 0.174[b] | 0.217[a] | 0.220[a] | NA | NR |
| Age | 0.236[a] | 0.157 | 0.084 | –0.87 | NA |
| Sound exposure | 0.057 | 0.065 | 0.014 | 0.13 | –0.146 |

| | Annoyance outside | Annoyance inside | Sleep disturbance | Psychological distress | Age |
|---|---|---|---|---|---|
| Quiet, do notice turbine sound (n=118) | | | | | |
| Annoyance outside | NA | NR | NR | NR | NR |
| Annoyance inside | 0.783[a] | NA | NR | NR | NR |
| Sleep disturbance | 0.380[a] | 0.438[a] | NA | NR | NR |
| Psychological distress | 0.201[b] | 0.282[a] | 0.182[b] | NA | NR |
| Age | –0.027 | –0.012 | 0.045 | –0.65 | NA |
| Sound exposure | 0.533 | 0.382[a] | 0.200[b] | 0.208[b] | 0.007 |

[a] $p<0.01$
[b] $p<0.05$

<table>
<tr><td>Exposure group [21]<br>See ‘Adverse effect outcomes’ [20].</td><td>Control group [22]<br>NA</td><td>Measure of effect / effect size [23]<br>95% CI [25]<br>See [20].</td><td>Harms (NNH) [24]<br>95% CI [25]<br>See [20].</td></tr>
<tr><td colspan="2">Public health importance (1–4) [26]<br>Unable to determine according to NHMRC ranking criteria.</td><td colspan="2">Relevance (1–5) [27]<br>5</td></tr>
<tr><td colspan="4">Comments [28]<br>This study was cross-sectional in design. This does not permit any conclusions regarding causation between health outcomes and noise exposure from turbines; that is, it is unknown whether the self-reported health outcomes occurred prior to or after exposure. Annoyance was considered, but it is not a health outcome and it is uncertain whether it is associated with stress which may be a mediating variable for health. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.</td></tr>
</table>

<table>
<tr><td colspan="3">ARTICLE DETAILS      Study NL-07</td></tr>
<tr><td colspan="3">Reference [1]<br>Pedersen, E, van den Berg, F, Bakker, R & Bouma, J 2009, 'Response to noise from modern wind farms in The Netherlands', Journal of the Acoustical Society of America, vol. 126, no. 2, pp. 634–643.</td></tr>
<tr><td colspan="3">Affiliation/source of funds [2]<br>Halmstad University and University of Gothenburg, Halmstad, Sweden; University of Groningen and GGD Amsterdam, The Netherlands; University Medical Centre Groningen, University of Groningen, Groningen, The Netherlands.<br>Funded through the European Union as a Specific Support Action, Contract No. 0044628.</td></tr>
<tr><td>Study design [3]<br>Cross-sectional study.</td><td>Level of evidence [4]<br>IV</td><td>Location/setting [5]<br>Areas in The Netherlands with ≥2 wind turbines of power ≥500 kW.<br>Proximity/distance:<br>Study population sampled from addresses within 2.5 km of a wind turbine with a second turbine <500 m from the first turbine.</td></tr>
</table>

<table>
<tr><td>Exposure description [6]<br>Wind farm details:<br>≥2 wind turbines of power ≥500 kW.<br>Specific exposure details:<br>A-weighted sound power levels (dB(A)) in octave bands at 8 m/s wind speed at 10 m height in a neutral atmosphere for all wind turbines were obtained from</td><td>Control(s) description [8]<br>No non-exposed groups were included in the study.<br>A distribution of participant characteristics (incomplete) across different sound level exposures was included (see ‘Specific exposure details’).<br>Sample size [9]</td></tr>
</table>

| | |
|---|---|
| consultancies, manufacturers and local authorities; or, where data were unavailable (older/smaller machines), the sound power level of a turbine with the same dimensions and electrical output was used; propagation of sound from turbines was calculated in accordance with the ISO standard model (see ISO 1996, 'Attenuation of sound during propagation outdoors. Part 2: General method of calculation', ISO 9613-2, International Organization for Standardization, Geneva).<br>**Sample size [7]**<br>Respondents, n=725; non-respondents, n=1223; response rate 37%. | See 'Population characteristics'.<br><br>Survey sample selected from addresses provided by Land Registry Office – for each subgroup either a random sample was selected or all addresses that matched postcodes within 2.5 km of selected wind turbines. Subgroups were: rural area, rural area with a major road, densely populated built-up area. |

**Population characteristics [10]**

**Exposure group:**

| | Estimated A-weighted sound pressure intervals in dB(A)[a] | | | | | |
|---|---|---|---|---|---|---|
| | <30 | 30–35 | 35–40 | 40–45 | >45 | Total |
| Sample, n | 473 | 494 | 502 | 282 | 197 | 1948 |
| Respondents, n | 185 | 219 | 162 | 94 | 65 | 725 |
| Response rate, % | 39 | 44 | 32 | 33 | 33 | 37 |

[a] These are the intervals as reported by the authors. Note that the intervals are not mutually exclusive, which limits conclusions based on analysis of different categories of sound pressure exposure. For further details regarding the utility/relevance of results included in this paper, see 'Outcomes measured'.

| | |
|---|---|
| **Length of follow-up [11]**<br>NA (cross-sectional study) | **Outcome(s) measured and/or analyses undertaken [12]**<br>Results analysed according to five wind turbine estimated noise exposure categories in 5-dB(A) intervals; however, clinical importance of endpoints chosen for this study is difficult to determine ie annoyance is not a health effect.<br>Outcomes measured were:<br>Response (do not notice / annoyance) to wind turbine noise outdoors and indoors, and attitude to wind turbines. |
| **INTERNAL VALIDITY**<br>**Confounding subscale [13]**<br>***Comment on sources of confounding:***<br>Adjustments made for area type (rural/urban), terrain (e.g. built up/main road), economic benefit from turbines, turbine visibility, background noise, noise sensitivity, attitude to turbines. Covariates varied | **EXTERNAL VALIDITY**<br>**Generalisability [15]**<br>Survey of households within 2.5 km of wind turbines; potential for differences between the total population living near the included wind farms and those that responded to questionnaire. |

between the analyses. Plausible confounders that were not addressed included socioeconomic status, age, gender, chronic disease and risk factors for chronic disease, occupation, education and employment.

**Bias subscale [14]**

***Comment on sources of bias:***
Sample selection bias is more likely with response rates below 70%. Response rate in this study was 37%. Masking of study intent was attempted to reduce recall bias—unclear if successful. Non-responder analysis conducted but no details on 'responding non-responder' characteristics.

**Applicability [16]**

Unknown whether the population characteristics and the wind turbine exposures of those living near wind farms in The Netherlands are comparable to those living near wind farms in Australia.

**Reporting subscale [17]**

***Comment on quality of reporting:***
Inadequate reporting on distribution of participant characteristics across the nominated estimated sound exposure levels (only an overall measure for mean age and sex) and did not provide any demographic information on non-responders.

**Chance [18]**

Statistical testing focused on prediction of annoyance. Multiple tests undertaken. There was the possibility of spurious significant associations because of the multiple statistical analyses undertaken.

**Overall quality assessment (descriptive) [19]**

On the basis of the Internal Validity assessment made above, and the detailed critical appraisal of the study given in Table 7, this study is considered poor quality for the purpose of this review.

There was some adjustment for potential confounding, although some plausible confounders were not addressed. There is potential for recall bias and outcome misclassification due to uncertainty in the effectiveness of masked study intent and inclusion of non-standard survey questions, respectively. There is a high risk of exposure misclassification (time and person criteria not well-defined) and statistically significant associations occurring due to chance (multiple statistical tests and no Bonferroni correction).

## RESULTS

**Adverse effect outcomes [20]**

*Response to wind turbine noise outdoors or indoors, proportion of respondents (n=708) according to 5-dB(A) sound level intervals.*

| | Predicted A-weighted sound pressure levels, dB(A)[a] | | | | |
|---|---|---|---|---|---|
| | <30 | 30–35 | 35–40 | 40–45 | >45 |
| Outdoors, n | 178 | 213 | 159 | 93 | 65 |
| Do not notice | 75 [68,81] | 46 [40,53] | 21 [16,28] | 13 [8,21] | 8 [3,17] |
| Notice, not annoyed | 20 [15,27] | 36 [30,43] | 41 [34,49] | 46 [36,56] | 58 [46,70] |
| Slightly annoyed | 2 [1,6] | 10 [7,15] | 20 [15,27] | 23 [15,32] | 22 [13,33] |
| Rather annoyed | 1 [0,4] | 6 [4,10] | 12 [8,18] | 6 [3,13] | 6 [2,15] |
| Very annoyed | 1 [0,4] | 1 [0,4] | 6 [3,10] | 12 [7,20] | 6 [2,15] |
| Indoors, n | 178 | 203 | 159 | 93 | 65 |

| | | | | | |
|---|---|---|---|---|---|
| Do not notice | 87 [81,91] | 73 [67,79] | 61 [53,68] | 37 [28,47] | 46 [35,58] |
| Notice, not annoyed | 11 [7,17] | 15 [11,20] | 22 [16,29] | 31 [22,31] | 38 [28,51] |
| Slightly annoyed | 1 [0,4] | 8 [5,12] | 9 [6,15] | 16 [10,25] | 9 [4,19] |
| Rather annoyed | 0 [0,2] | 3 [1,6] | 4 [2,8] | 6 [3,13] | 5 [2,13] |
| Very annoyed | 1 [0,4] | 1 [0,4] | 4 [2,8] | 10 [5,17] | 2 [0,8] |

Values are % [95% CI] unless otherwise specified.
[a] These are the intervals as reported by the authors. Note that the intervals are not mutually exclusive.

*Distributions of possible confounding factors in relation to 5-dB(A) sound level intervals, proportion of respondents (n=725) per sound level interval*

| Predicted A-weighted sound pressure levels, dB(A)[a] | <30 n=185 | 30–35 n=219 | 35–40 n=162 | 40–45 n=94 | >45 n=65 |
|---|---|---|---|---|---|
| Economic benefits, % | 2 | 3 | 10 | 34 | 67 |
| Situational parameters, % | | | | | |
| Wind turbines visible | 35 | 60 | 90 | 89 | 100 |
| Rural area | 36 | 30 | 46 | 43 | 52 |
| Rural area with main road | 27 | 32 | 36 | 38 | 46 |
| Built-up area | 37 | 38 | 17 | 19 | 2 |
| Subjective variables, % [95% CI] | | | | | |
| Noise sensitive | 36 [29,43] | 25 [19,31] | 31 [24,38] | 31 [22,41] | 23 [15,35] |
| Negative attitude to turbines | 10 [7,16] | 14 [10,19] | 19 [13,25] | 17 [11,26] | 9 [4,19] |
| Negative visual attitude | 33 [26,40] | 36 [30,43] | 45 [37,52] | 39 [30,49] | 20 [12,41] |

Values are % [95% CI] unless otherwise specified.
[a] These are the intervals as reported by the authors. Note that the intervals are not mutually exclusive.

*Results of logistic regression models using response variables 'do not notice/notice' and 'not annoyed/annoyed' (exposure variable 'sound pressure level' and situational factors were used as independent variables, n=680)*

| | Estimate (B)[a] | SE[b] | p value | Exp(b)[c] |
|---|---|---|---|---|
| Do not notice *vs* notice (H-L)[d] (p=0.721) | | | | |
| Sound pressure level, dB(A) | 0.17 | 0.022 | <0.001 | 1.2 |
| Economic benefit (no/yes) | –0.04 | 0.376 | 0.911 | 1.0 |
| Visibility (no/yes) | 1.40 | 0.214 | <0.001 | 4.1 |
| Area type (reference: rural) | | | | |
| Rural with main road | –0.74 | 0.231 | <0.01 | 0.5 |
| Built-up | –0.18 | 0.240 | 0.451 | 0.8 |
| Not annoyed *vs* annoyed (H-L)[d] (p=0.199) | | | | |
| Sound pressure level, dB(A) | 0.13 | 0.027 | <0.001 | 1.1 |
| Economic benefit (no/yes) | –2.77 | 0.665 | <0.001 | 0.1 |
| Visibility (no/yes) | 2.62 | 0.740 | <0.001 | 13.7 |
| Area type (reference: rural) | | | | |
| Rural with main road | –1.07 | 0.372 | <0.01 | 0.3 |
| Built-up | 0.65 | 0.321 | <0.05 | 1.9 |

[a] Coefficients of the independent variables in the logistic regression.
[b] Standard errors of the coefficients.
[c] The exponential function of the coefficients of the independent variables in the logistic regression, which corresponds to the odds ratio.
[d] Hosmer-Lemeshow goodness-of-fit test; p value >0.05 indicates that there is no statistically significant difference between the modelled and observed data.

*Correlations between sound pressure levels, response (5-point scale from 'do not notice' to 'very annoyed') and subjective variables*[a]

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1. Sound pressure level, dB(A) | NA | NR | NR | NR |
| 2. Response (5-point scale) | 0.51[b] | NA | NR | NR |
| 3. Noise sensitivity (5-point scale) | –0.01 | 0.14[b] | NA | NR |
| 4. General attitude (5-point scale) | –0.03 | 0.24[b] | 0.14[b] | NA |
| 5. Visual attitude (5-point scale) | –0.01 | 0.29[b] | 0.26[b] | 0.65[b] |

[a] Spearman's rank correlation test
[b] p<0.001
Abbreviations: NA = not applicable; NR = not reported

*Results of logistic regression model with response variables 'not annoyed/annoyed', the exposure variable 'sound pressure level' and individual factors as independent variables (n=670)*

| | Estimate (B)[a] | SE[b] | p value | Exp(b)[c] |
|---|---|---|---|---|
| Not annoyed vs annoyed (H-L)[d] (p=0.977) | | | | |
| Sound pressure level, dB(A) | 0.10 | 0.025 | <0.001 | 1.1 |
| Noise sensitivity (5-point scale) | 0.35 | 0.138 | <0.05 | 1.4 |
| General attitude (5-point scale) | 0.54 | 0.172 | <0.01 | 1.7 |
| Visual attitude (5-point scale) | 1.04 | 0.215 | <0.001 | 2.8 |

[a] Coefficients of the independent variables in the logistic regression.
[b] Standard errors of the coefficients.
[c] The exponential function of the coefficients of the independent variables in the logistic regression, which corresponds to the odds ratio.
[d] Hosmer-Lemeshow goodness-of-fit test; p value >0.05 indicates that there is no statistically significant difference between the modelled and observed data.

| **Exposure group [21]** | **Control group [22]** | **Measure of effect / effect size [23]** | **Harms (NNH) [24]** |
|---|---|---|---|
| See 'Adverse effect outcomes' [20]. | NA | **95% CI [25]** See 'Adverse effect outcomes' [20]. | **95% CI [25]** See [20]—although no health effects reported. |

| **Public health importance (1–4) [26]** | **Relevance (1–5) [27]** |
|---|---|
| Unable to determine as per NHMRC criteria. | 5 |

**Comments [28]**

This study was cross-sectional in design. Annoyance was considered, but it is not a health outcome and it is uncertain whether it is associated with stress which may be a mediating variable for health. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.

| **ARTICLE DETAILS** | | **Study NL-07** |
|---|---|---|
| **Reference [1]**<br><br>**Van den Berg**, G, Pedersen, E, Bouma, J & Bakker, R **2008**, *Project WINDFARM perception: visual and acoustic impact of wind turbine farms on residents*, University of Groningen, FP6-2005-Science-and-Society-20, Specific Support Action, Project no. 044628. | | |
| **Affiliation/source of funds [2]**<br><br>Faculty of Mathematics and Natural Sciences, University of Groningen; Department of Public Health and Community Medicine, Göteborg University; Science Shop for Medicine and Public Health, University Medical Centre Groningen; Northern Centre for Health Care Research, University Medical Centre Groningen.<br><br>Funded by the European Union. | | |
| **Study design [3]**<br><br>Cross-sectional study. | **Level of evidence [4]**<br><br>IV | **Location/setting [5]**<br><br>Rural and urban settings in The Netherlands with flat topography; rural environments were classified according to whether or not a major road was located within 500 m of the closest wind turbine.<br><br>**Proximity/distance:**<br>Study population sampled from addresses within 2.5 km of a wind turbine with a second turbine <500 m from the first turbine. |

| **Exposure description [6]** | **Control(s) description [8]** |
|---|---|
| **Wind farm details:**<br>Turbine number within proximity of any given residence surveyed, n≥2; the two closest turbines were required to have nominal electric power ≥500 kW, but additional turbines were included in analysis regardless of power output.<br><br>**Specific exposure details:**<br>Sound pressure in A-weighted decibels (dB(A))[a] outside residences averaged over time with 8 m/s downwind; range = 21–54 dB(A), mean = 35 dB(A).<br><br>Frequency range of sound not reported; i.e., exposure profile in terms of audible noise versus infrasound not analysed.<br><br>[a] Sound power levels collected from reports by consultancies, manufacturers and local authorities, or, where data were unavailable (older/smaller machines), the sound power level of a turbine with the same dimensions and electrical output was used; propagation of sound from turbines was calculated in | No non-exposed groups were included in the study.<br><br>A distribution of different sound level exposures was included (see 'Specific exposure details' and 'Population characteristics').<br><br>**Sample size [9]**<br><br>See 'Population characteristics'.<br><br>Survey sample selected from addresses provided by Land Registry Office – for each subgroup either a random sample was selected or all addresses that matched postcodes within 2.5 km of selected wind turbines. Subgroups were: rural area, rural area with a major road, densely populated built-up area. |

accordance with the ISO standard model (see ISO 1996, 'Attenuation of sound during propagation outdoors. Part 2: General method of calculation', ISO 9613-2, International Organization for Standardization, Geneva).

**Sample size [7]**

Total, n=1948; respondents, n=725; non-respondents, n=1223; response rate 37%.

**Population characteristics [10]**

| | Estimated sound pressure level, in dB(A) | | | | | |
|---|---|---|---|---|---|---|
| | <30 | 30–35 | 36–40 | 41–45 | >45 | Total |
| Study sample, n | 491 | 589 | 421 | 250 | 197 | 1948 |
| Respondents, n (%) | | | | | | |
| Built-up area | 68 (37) | 84 (38) | 28 (17) | 18 (19) | 1 (2) | 199 (23) |
| Rural with main road | 50 (27) | 70 (32) | 59 (38) | 36 (38) | 30 (46) | 245 (36) |
| Rural without main road | 67 (36) | 65 (30) | 75 (47) | 40 (43) | 34 (52) | 281 (41) |
| Total | 185 (38) | 219 (37) | 162 (38) | 94 (38) | 65 (33) | 725 (100) |
| Age, mean (years) | NR | NR | NR | NR | NR | 51 |
| Sex, % male | NR | NR | NR | NR | NR | 51 |

**Length of follow-up [11]**

NA (cross-sectional study design)

**Outcome(s) measured and/or analyses undertaken [12]**

(a) psychological distress as determined by self-administered General Health Questionnaire (GHQ-12) [validated];
(b) chronic disease and a range of specific health states (see 'Results'), stress and sleep quality as per non-validated survey constructed by van den Berg et al.;
(c) relationship between turbine sound exposure and self-reported health states (including chronic disease) considered at (b);
(d) annoyance due to visual factors and vibration.

<table>
<tr>
<td>
INTERNAL VALIDITY<br><br>
Confounding subscale [13]<br><br>
Comment on sources of confounding:<br>
Few details on characteristics of participating population were reported. Adjustments made for influence of age, gender, education, employment, terrain, type of dwelling, urbanisation, economic benefit from turbines, background noise, noise sensitivity, attitude to turbines and turbine visibility. Findings may be partly explained by differences in levels of background sound between rural and urban areas. Covariates varied between analyses. Plausible confounders that were not addressed included socioeconomic status, chronic disease and risk factors for chronic disease, and occupation.<br><br>
Bias subscale [14]<br><br>
Comment on sources of bias:<br>
High potential for sample selection bias due to low response rate. It is uncertain whether participants were effectively masked regarding the purpose of the survey (recall bias). Equal weight was given to questions regarding other environmental factors but it is unclear whether study intent was known, leading to the possibility of responder bias (conscious or unconscious). Non-responder analysis conducted but only on 95 of the 200 randomly selected non-responders (non-responders=1223), so may not be representative.
</td>
<td>
EXTERNAL VALIDITY<br><br>
Generalisability [15]<br><br>
Survey mailed to a sample of households within 2.5 km of wind turbines; potential for differences between the total population living near the included wind farms and those that responded to questionnaire.<br><br>
Applicability [16]<br><br>
Unknown whether the population characteristics and the wind turbine exposures of those living near wind farms in The Netherlands are comparable to those living near wind farms in Australia.
</td>
</tr>
<tr>
<td colspan="2">
Reporting subscale [17]<br><br>
Comment on quality of reporting:<br>
Main deficit is that information was not provided on characteristics of non-responders. Overall, though, reporting of study results in the full report was good.
</td>
</tr>
<tr>
<td colspan="2">
Chance [18]<br><br>
Statistical adjustments for undertaking multiple statistical tests were not reported.
</td>
</tr>
<tr>
<td colspan="2">
Overall quality assessment (descriptive) [19]<br><br>
On the basis of the Internal Validity assessment made above, and the detailed critical appraisal of the study given in Table 7, this study is considered poor quality for the purpose of this review.<br><br>
There was some adjustment for potential confounding, although a few plausible confounders were not addressed. There is potential for recall bias and outcome misclassification due to uncertainty in the effectiveness of masked study intent and inclusion of non-standard survey questions, respectively. There is a high risk of exposure misclassification (time criterion was not well-defined), sample selection bias (37% response rate) and statistically significant associations occurring due to chance (multiple statistical tests and no Bonferroni correction).
</td>
</tr>
</table>

## RESULTS

**Adverse effect outcomes [20]**

*Self-reported health and sleep in relation to estimated sound pressure level.*

| | Estimated sound pressure level, in dB(A) | | | | | |
|---|---|---|---|---|---|---|
| | <30 | 30–35 | 36–40 | 41–45 | >45 | Total |
| Chronic disease (n=717), % | 32 | 25 | 25 | 18 | 15 | 25 |
| Diabetes (n=725), % | 4 | 4 | 4 | 2 | 3 | 4 |
| High blood pressure (n=725), % | 9 | 13 | 9 | 6 | 2 | 9 |
| Tinnitus (n=725), % | 4 | 3 | 1 | 1 | 2 | 2 |
| Hearing impairment (n=725), % | 4 | 6 | 3 | 3 | 2 | 4 |
| Cardiovascular disease (n=725), % | 6 | 7 | 8 | 1 | 0 | 6 |
| Migraine (n=725), % | 4 | 2 | 2 | 1 | 0 | 2 |
| GHQ-12 score (n=656), mean±SD | 3.2±2.78 | 3.1±2.66 | 3.8±2.91 | 3.8±2.81 | 3.6±2.76 | 3.4±2.79 |
| Stress score (n=656), mean±SD | 0.1±1.04 | –0.1±0.93 | 0.1±0.9 | 0.0±0.91 | –0.1±1.02 | 0.0±0.0 |
| Sleep quality | | | | | | |
| Difficulty falling asleep [a] (n=710), % | 36 | 31 | 28 | 32 | 16 | 30 |
| Interrupted sleep [a] (n=718), % | 21 | 26 | 26 | 26 | 28 | 25 |

[a] At least once a month.

*Relationship between estimated sound exposure and self-reported health states including chronic disease (logistic regression) for all respondents.*

Note: these results comprise part of the data shown in results tables for Pedersen et al. (2009) (excluding migraine), which adjusted for age, sex and economic benefits.

| | Odds ratio | 95% CI |
|---|---|---|
| Chronic disease: | 0.98 | [0.95, 1.01] |
| Diabetes | 1.00 | [0.92, 1.09] |
| High blood pressure | 1.01 | [0.96, 1.06] |
| Tinnitus | 0.94 | [0.85, 1.04] |
| Hearing impairment | 1.01 | [0.94, 1.10] |
| Cardiovascular disease | 0.98 | [0.91, 1.05] |
| Migraine | 0.93 | [0.83, 1.04] |

*Annoyance due to visual factors and vibration for all respondents (not stratified by sound exposure group.)*

| | Blinking shadows indoors | Moving shadows outdoors | Movement of rotor blades | Changed view | Vibrations |
|---|---|---|---|---|---|
| Respondents annoyed, n (%) | | | | | |
| Slightly | 75 (11) | 63 (9) | 70 (10) | 91 (14) | 18 (3) |
| Rather | 20 (3) | 15 (2) | 30 (5) | 48 (7) | 4 (1) |
| Very | 19 (3) | 23 (4) | 27 (4) | 42 (6) | 3 (0) |
| Total annoyed | 114/669 (17) | 101/665 (15) | 127/667 (19) | 181/665 (27) | 25/638 (4) |
| Frequency of annoyance, n (%) | | | | | |
| Almost never | 529 (80) | 520 (79) | 498 (76) | 442 (68) | 615 (96) |
| ≥Once in past year | 44 (7) | 43 (7) | 31 (5) | 46 (7) | 9 (1) |
| ≥Once per month | 38 (6) | 37 (6) | 27 (4) | 29 (4) | 7 (1) |
| ≥Once per week | 30 (5) | 27 (4) | 26 (4) | 22 (3) | 7 (1) |
| Almost daily | 23 (3) | 32 (5) | 73 (11) | 113 (17) | 6 (1) |
| Total | 663 (100) | 659 (100) | 665 (100) | 652 (100) | 644 (100) |

| Exposure group [21] | Control group [22] | Measure of effect / effect size [23]<br>95% CI [25] | Harms (NNH) [24]<br>95% CI [25] |
|---|---|---|---|
| See 'Adverse effect outcomes' [20]. | NA | See [20]. | See [20]. |

| Public health importance (1–4) [26] | Relevance (1–5) [27] |
|---|---|
| Ranked 3 for overall chronic disease outcome. Ranked 3 or 4 for health outcomes taken singly. | 1 |

**Comments [28]**

This study was cross-sectional in design. This does not permit any conclusions regarding causation between health outcomes and noise exposure from turbines; that is, it is unknown whether the self-reported health outcomes occurred prior to or after exposure. Health outcomes did not appear related to estimated sound exposure. Annoyance was considered, but it is not a health outcome and it is uncertain whether it is associated with stress which may be a mediating variable for health. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.

## Ontario, Canada, study

<table>
<tr><td colspan="3">ARTICLE DETAILS</td></tr>
<tr><td colspan="3">Reference [1]<br>Krogh, CME, Gillis, L, Kouwen, N & Aramini, J 2011, 'WindVOiCe, a self-reporting survey: adverse health effects, industrial wind turbines, and the need for vigilance monitoring', Bulletin of Science, Technology & Society, vol. 31(4), pp. 334–345.</td></tr>
<tr><td colspan="3">Affiliation/source of funds [2]<br>Killaloe, Flesherton, University of Waterloo, Waterloo and Intelligent Health Solutions, Fergus, Ontario, Canada.</td></tr>
<tr><td>Study design [3]<br>Cross-sectional study</td><td>Level of evidence [4]<br>IV</td><td>Location/setting [5]<br>Residents in five project areas in Ontario, Canada, where adverse health effects had been anecdotally reported:<br>Melancthon Phase 1 and 2 (Shelburne), Canadian Hydro Wind Developers (Shelburne), Kingsbridge 1 Wind Power (Goderich), Kruger Energy Port Alma (Port Alma), Ripley Wind Power (Ripley), Enbridge Ontario Wind Farm (Kincardine) and Erie Shores Wind Farm (Port Burwell).<br><br>Proximity/distance:<br>Distance to nearest wind turbine was divided into four groups based on natural break-points among the participants: 350–499 m, 500–699 m, 700–899 m, and 900–2400 m.</td></tr>
<tr><td>Exposure description [6]<br>Wind farm details sourced from:<br><http://en.wikipedia.org/wiki/List_of_wind_farms_in_Canada><br><br>Melancthon Phase 1 and 2 (Amaranth), commenced operation in March 2006<br>133 General Electric SLE 1.5-MW turbines, sited in a farming community<br>Turbine height = 80 m<br>Rotor diameter = 77 m<br><br>Kingsbridge 1 Wind Power (Goderich), commenced</td><td colspan="2">Control(s) description [8]<br>No non-exposed groups were included in the study.<br>Sample size [9]<br>See ‘Population characteristics’.</td></tr>
</table>

| | |
|---|---|
| operation in March 2006<br>22 Vestas V80 1.8-MW turbines, sited on the southeast shore of Lake Huron<br>Turbine height = 78 m<br>Rotor diameter = 80 m<br><br>*Kruger Energy Port Alma (Port Alma),* commenced operation in November 2008<br>44 Siemens 2.3-MW Mark II turbines, sited on the north shore of Lake Erie<br>Turbine height = 80 m<br>Rotor diameter = 82.5 m<br><br>*Ripley Wind Power (Ripley),* commenced operation in December 2007<br>38 Enercon E-82 2.0-MW turbines, sited along the shore of Lake Huron<br>Turbine height = 79 m<br>Rotor diameter = 82 m<br><br>*Enbridge Ontario Wind Farm (Kincardine),* commenced operation in August 2008<br>110 Vestas V82 1.65-MW turbines, sited along the shore of Lake Huron<br>Turbine height = 80 m<br>Rotor diameter = 82 m<br><br>*Erie Shores Wind Farm (Port Burwell),* commenced operation in April 2006<br>66 General Electric SLE 1.5-MW turbines, sited along the shore of Lake Erie<br>Turbine height = 80 m<br>Rotor diameter = 77 m<br><br>**Specific exposure details:**<br>Not reported.<br><br>**Sample size [7]**<br><br>A Health Survey Contact Flyer was distributed by Canada Post and hand-delivered by volunteers to mailboxes in the areas where the wind turbines were located.<br>n=103 respondents; 6 were excluded; 4 were under 18 years of age and 2 were much further away (5 km) than the remaining respondents (350–2400 m).<br><br>Respondents were divided into subgroups according to distance from nearest wind turbine:<br>24% adults living mean 428 m (range 350–490 m) from nearest wind turbine<br>23% adults living mean 587 m (range 500–67 m) from | |

<table>
<tr><td>nearest wind turbine<br>30% adults living mean 769 m (range 700–808 m) from nearest wind turbine<br>17% adults living mean 1154 m (range 900–2400 m) from nearest wind turbine</td><td></td></tr>
<tr><td colspan="2">Population characteristics [10]<br>Exposure group:<br>n=103 respondents; mean age = 52 years (range 18–83); female = 52%.<br>Control group(s):<br>None.</td></tr>
<tr><td>Length of follow-up [11]<br>NA (cross-sectional study).<br>Length of exposure:<br>Wind farms commenced operation between March 2006 and November 2008 (see details above). Survey started in March 2009.</td><td>Outcome(s) measured and/or analyses undertaken [12]<br>Health outcomes measured by self-reporting survey.</td></tr>
<tr><td>INTERNAL VALIDITY<br>Confounding subscale [13]<br>Comment on sources of confounding:<br>Few details on participant characteristics and none for non-responders. Only gender was taken into account for some analyses. Many other plausible confounders not addressed ie economic factors, age, chronic disease and risk factors for chronic disease, occupation, education, employment, terrain, urbanisation, background noise, and turbine visibility.<br><br>Bias subscale [14]<br>Comment on sources of bias:<br>The intent of the study was not masked from survey recipients (recall bias). Sampling area was chosen because adverse health effects had been reported there (sample selection bias). Possible clustering by household as multiple adults from same household were able to respond (sample selection bias).</td><td>EXTERNAL VALIDITY<br>Generalisability [15]<br>Potential for differences between the total population living near the included wind farms and those that participated in the survey.<br>Applicability [16]<br>Uncertain whether the population characteristics and the wind turbine exposures of those living near wind farms in Ontario, Canada, are applicable to those living near wind farms in Australia.</td></tr>
<tr><td colspan="2">Reporting subscale [17]<br>Comment on quality of reporting: No reporting on participant characteristics (except age and gender of all participants), or on the characteristics of non-responders. No reporting on survey response rate.</td></tr>
<tr><td colspan="2">Chance [18]<br>The possibility of spurious significant associations arising by chance cannot be excluded as multiple statistical</td></tr>
</table>

tests were conducted.

**Overall quality assessment (descriptive) [19]**

On the basis of the Internal Validity assessment made above, and the detailed critical appraisal of the study given in Table 7, this study is considered poor quality for the purpose of this review.

There is potential for sample selection bias as the response rate was not reported. The outcomes were patient-relevant but not reliably measured. There is a high risk of exposure misclassification (time and personal characteristics criteria were not well-defined), recall bias (study intent not masked), outcome misclassification (non-validated survey questions), confounding and statistically significant associations occurring due to chance (multiple statistical tests and no Bonferroni correction).

**RESULTS**

| **Adverse effect outcomes [20]** | **Exposure group [21]** | | | | | **Control group [22]** | **Harms (NNH) [24] 95% CI** |
|---|---|---|---|---|---|---|---|
| | | | | | | **Measure of effect / effect size [23]** | NC |
| | | | | | | **95% CI [25]** | |
| | **Mean distance from turbine: Subgroups:** | | | | **Total:** | p (Fisher's | |
| | **428 m** | **587 m** | **769 m** | **1154 m** | **707 m** | exact) | |
| Altered quality of life | 96% | 96% | 100% | 94% | 97% | p = 1.00 | |
| Altered health | 93% | 96% | 87% | 82% | 90% | p = 0.19 | |
| Disturbed sleep | 78% | 78% | 60% | 59% | 69% | p = 0.08 | |
| Excessive tiredness | 89% | 83% | 63% | 71% | 76% | p = 0.03 | |
| Increased headaches | 74% | 65% | 60% | 41% | 62% | p = 0.10 | |
| Migraines | 22% | 13% | 13% | 0% | 13% | p = 0.24 | |
| Hearing problems | 22% | 57% | 27% | 41% | 35% | p = 0.67 | |
| Tinnitus | 59% | 61% | 33% | 41% | 56% | p = 0.42 | |
| Heart palpitations | 26% | 39% | 33% | 37% | 34% | p = 0.68 | |
| Stress | 74% | 57% | 70% | 76% | 69% | p = 0.52 | |
| Anxiety | 52% | 57% | 40% | 65% | 52% | p = 0.68 | |
| Depression | 44% | 48% | 33% | 41% | 41% | p = 0.41 | |
| Distress | 74% | 61% | 73% | 82% | 72% | p = 0.38 | |
| Approached doctor | 37% | 39% | 49% | 35% | 38% | p = 1.00 | |
| | **Public health importance (1–4) [26]** | | | | | **Relevance (1–5) [27]** | |
| | Cannot be determined based on NHMRC criteria. | | | | | 1 | |

**Comments [28]**

Nearly all respondents suffered from altered quality of life and/or altered health. However, this study was cross-sectional in design and so does not permit any conclusions regarding causation between health outcomes and noise exposure from turbines; that is, it is unknown whether the self-reported health outcomes occurred prior to or after exposure.

It is unknown how many people were approached but did not respond to the survey. It is possible that those suffering no ill effects did not respond to this survey as it required contacting the WindVOiCe survey team to participate. The only statistically significant difference between groups near and far from the turbines was excessive tiredness. Although not statistically significant (and an unadjusted analysis), the number of people suffering from self-reported headaches, migraines and sleep disturbances had a linear relationship with distance from nearest wind turbine. The number of people suffering from self-reported tinnitus also <u>decreased</u> if living further from, as opposed to closer to, the nearest turbine.

The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.

## Australian study

### ARTICLE DETAILS

**Reference [1]**

**Morris**, M **2012**. 'Waterloo Wind Farm survey'. Available at: <http://www.wind-watch.org/news/>.

**Affiliation/source of funds [2]**

'Mid North Wind Farm Awareness' member.

| Study design [3] | Level of evidence [4] | Location/setting [5] |
|---|---|---|
| Cross-sectional survey | IV | Waterloo Wind Farm, North Mount Lofty Ranges, South Australia.<br>**Proximity/distance:**<br>Within 10 km. |

**Exposure description [6]**

**Wind farm details, sourced from:**
<http://en.wikipedia.org/wiki/Wind_power_in_South_Australia#Waterloo_Wind_Farm_.28111_MW.29>
and
<http://www.energyaustralia.com.au/about-us/what-we-do/generation-assets/waterloo-wind-farm>
37 turbines (Vestas V90-3.0 MW) sited on a ridgeline
Turbine height = 80 m
Rotor diameter = 90 m

**Specific exposure details:**
Typical noise exposure range not reported.

**Sample size [7]**

n=230 households received an anonymous survey
Responders in 0–10 km range:
n=93 households, n=270 residents
Response rate = 40%.
Subgroup in 0–5 km range:
n=41 households, n=92 residents

**Control(s) description [8]**

No non-exposed groups were included in the study.

Participation determined by distance from wind turbines (0–10 km), with a subgroup of participants 0–5 km from turbines.

**Sample size [9]**

NA

**Population characteristics [10]**

**Exposure group:**
Households within approximately 10 km of the Waterloo Wind Farm, SA.

**Control group(s):**
None.

<table>
<tr><td>

**Length of follow-up [11]**

NA

**Length of exposure:**
Wind farm commenced operation in October 2010. Survey conducted in April 2012.

</td><td>

**Outcome(s) measured and/or analyses undertaken [12]**

Annoyed by flickering, disturbed sleep, affected by noise (includes: cannot get to sleep, get woken up, cannot get back to sleep, wake up in a panic, wake up in a sweat, broken/disturbed sleep, ear pain/ear pressure/tinnitus, headache, nausea, had to move away to get sleep, high blood pressure when wake up, ears hurt which makes sleep difficult).

</td></tr>
<tr><td>

**INTERNAL VALIDITY**

**Confounding subscale [13]**

***Comment on sources of confounding:***
No details on responder characteristics or plausible confounders e.g. socioeconomic status, economic factors, age, gender, chronic disease and risk factors for chronic disease, occupation, education, employment, urbanisation, background noise, wind turbine visibility and terrain.

**Bias subscale [14]**

***Comment on sources of bias:***
There was no clear definition of what 'affected by noise' included. Self-reporting survey, hence no independent confirmation of claimed adverse effects. Differences between responders and non-responders were not assessed. Study intent was not masked for survey recipients.

</td><td>

**EXTERNAL VALIDITY**

**Generalisability [15]**

Survey distributed to all households within proximity of a wind farm / wind turbines.

**Applicability [16]**

Survey conducted in Australia.

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<tr><td colspan="2">

**Reporting subscale [17]**

***Comment on quality of reporting:***
There was no clear description of main outcomes, participant characteristics, exposure level or any differences between responders and non-responders.

</td></tr>
<tr><td colspan="2">

**Chance [18]**

No data analysis.

</td></tr>
<tr><td colspan="2">

**Overall quality assessment (descriptive) [19]**

On the basis of the Internal Validity assessment made above, and the detailed critical appraisal of the study given in Table 7, this study is considered poor quality for the purpose of this review.

There is a high risk of exposure misclassification (time and personal characteristics criteria were not well-defined), recall bias (study intent not masked), sample selection bias (40% response rate), confounding (no statistical adjustments were made), and outcome misclassification (non-validated survey questions).

</td></tr>
</table>

| RESULTS | | | | |
|---|---|---|---|---|
| **Adverse effect outcomes [20]**<br>Distance from turbine:<br>Disturbed sleep<br>Seriously affected<br>Moderately affected | **Exposure group [21]**<br>0–10 km (all responders)<br>27/93 (29%)<br>7/44 (16%)<br>17/44 (39%) | **Subgroup [22]**<br>0–5 km (subgroup)<br>16/41 (39%)<br>6/25 (24%)<br>10/25 (40%) | **Measure of effect / effect size [23]**<br>**95% CI [25]**<br>NC | **Harms (NNH) [24]**<br>**95% CI [25]**<br>NC |
| | **Public health importance (1–4) [26]**<br>Not able to determine from the NHMRC criteria. | | **Relevance (1–5) [27]**<br>5 | |
| **Comments [28]**<br>The study was quasi-scientific and of poor quality. The study design, poor execution and analysis prevent any firm conclusions from being drawn. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects. | | | | |

# Maine, USA study

## ARTICLE DETAILS

**Reference [1]**

**Nissenbaum**, M, Aramini, J & Hanning, C **2012**, 'Effects of industrial wind turbine noise on sleep and health', *Noise & Health*, vol. 14, pp. 237–243.

**Affiliation/source of funds [2]**

Northern Maine Medical Center, Fort Kent, Maine, USA; Intelligent Health Solutions Inc., Fergus, Ontario Canada; University Hospitals of Leicester, Leicester, UK.

| Study design [3] | Level of evidence [4] | Location/setting [5] |
|---|---|---|
| Cross-sectional study. | IV | Residences of Mars Hill and Vinalhaven, Maine, USA.<br>**Proximity/distance:**<br>Exposed residences located within 1.5 km of nearest industrial wind turbine; control residences were located 3–7 km from nearest turbine. |

**Exposure description [6]**

**Wind farm details:**
*Mars Hill site*
28 General Electric 1.5-MW turbines, sited on a ridgeline.

*Vinalhaven site*
Cluster of 3 turbines of similar specification to Mars Hill site, sited on a flat tree covered island.

**Specific exposure details:**
Mars Hill full power measurements were derived from a four-season study.
Vinalhaven measurements taken in February 2010, during moderate-to-variable northwest winds with turbines at less than full power:

| Distance from turbine | *Mars Hill* Measured noise $LA_{eq,1\ hour}$ (range) | *Vinalhaven* Measured noise $LA_{eq,1\ hour}$ (range) |
|---|---|---|
| 366 | 49 (47–52) | 46 (38–49) |
| 595 | | 41 (39–49) |
| 640 | 44 (40–47) | |
| 762 | 43 (41–46) | |
| 869 | | 38 (32–41) |

**Control(s) description [8]**

See 'Proximity/distance' for details; whether this control group can be considered truly unexposed is uncertain as criteria for the present review do not specify a cut-off for exposure by distance, and this group may alternatively be considered as 'partially exposed'.

**Sample size [9]**

n=41 adult (>18 years of age) respondents among 41 adults identified to be living within 3–7 km from nearest turbine
n=25 living around Mars Hill
n=16 living around Vinalhaven.
Response rate = not reported.

| | | |
|---|---|---|
| 1037 | 41 (39–45) | |
| 1082 | | 36 (34–43) |
| 1799 | 37 (32–43) | |

**Sample size [7]**

n=38 adult (>18 years of age) respondents among 65 adults identified to be living within 1.5 km of nearest turbine
n=23 adults living mean 805 m (range 390 –1400 m) from Mars Hill
n=15 adults living mean 771 m (range 375–1000 m) from Vinalhaven.
Response rate = 58%.

**Population characteristics [10]**

| | **Distance range from turbines** | | | |
|---|---|---|---|---|
| | **Exposure group (near)** | | **Control group (far)** | |
| Distance (m) from nearest turbine, mean (range) | 601 (375–750) | 964 (751–1400) | 4181 (3300–5000) | 5800 (5300–6600) |
| Sample size, n | 18 | 20 | 14 | 27 |
| Household clusters, n | 11 | 12 | 10 | 23 |
| Age, years (mean) | 50 | 57 | 65 | 58 |
| Male, n (%) | 10 (55.6) | 12 (60) | 7 (50) | 11 (40.7) |

**Length of follow-up [11]**

NA (cross-sectional study).

**Length of exposure:**
Mars Hill commenced operation in March 2007.
Vinalhaven commenced operation in December 2009.
Survey conducted in March–July 2010.

**Outcome(s) measured and/or analyses undertaken [12]**

Sleep quality as determined by the Epworth Sleepiness Scale (ESS) and Pittsburgh Sleep Quality Index (PSQI); health as per responses to physical and mental health components of the Short Form (36) Health Survey, version 2 (SF-36v2). Questionnaires are validated.

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**INTERNAL VALIDITY**

**Confounding subscale [13]**

***Comment on sources of confounding:***
Few details on participant characteristics and none for non-responders.

Confounders taken into account included age, gender, site and household clustering. The impact of economic benefit from turbines was not controlled for despite the authors acknowledging that residents of Mars Hill and Vinalhaven benefited financially from wind farms in their area. Turbine visibility was not taken into account in the analysis. Other plausible confounders also not addressed e.g. socioeconomic status, chronic disease and risk factors for chronic disease, occupation, education, employment, terrain, urbanisation and background noise.

**Bias subscale [14]**

***Comment on sources of bias:***
It was not possible to mask participants to their exposure level to turbine noise but the intent of the survey was also not masked (recall bias). 58% response rate in exposed group (sample selection bias). The possibility of confounding due to differences in the distribution of economically benefiting residents in the ‘near’ and ‘far’ groups cannot be excluded.

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**EXTERNAL VALIDITY**

**Generalisability [15]**

Approached all adults identified as living in close proximity to the wind farms for intervention group.

**Applicability [16]**

Uncertain whether the population characteristics and the wind turbine exposures of those living near wind farms in Mars Hill and Vinalhaven in Maine, USA, are applicable to those living near wind farms in Australia.

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**Reporting subscale [17]**

***Comment on quality of reporting:***
Overall good reporting except for participant characteristics such as general state of health, previous depression, anxiety or sleep problems and the characteristics of non-responders.

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**Chance [18]**

The possibility of spurious significant associations arising by chance cannot be excluded as multiple statistical tests were conducted.

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**Overall quality assessment (descriptive) [19]**

Although exposure ascertainment was partly directly measured and there was good reporting of some study characteristics and adjustment for potential confounders, other plausible confounders were not measured or adjusted and the study intent was not masked. Outcome misclassification was less of a problem due to the use of validated instruments/scales. There is, therefore, a high risk of recall bias, sample selection bias, confounding, statistically significant associations occurring due to chance and exposure misclassification.

For further critical appraisal of the study, see Table 7.

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| **RESULTS** | | | | | | | **Harms (NNH) [24] 95% CI**<br>See [20]. |
|---|---|---|---|---|---|---|---|
| **Adverse effect outcomes [20]** | **Exposure group [21] (near)**<br>**Mean distance from turbine:**<br>**Subgroups:** | | | **Control group [22] (far)**<br>**Mean distance from turbine:**<br>**Subgroups:** | | | **Measure of effect / effect size [23]**<br>**95% CI [25]** |
| | **601 m** | **964 m** | **Total: 792 m** | **4181 m** | **5800 m** | **Total: 5248 m** | **Results for total group differences** |
| PSQI, mean | 8.7 | 7.0 | 7.8 | 6.6 | 5.6 | 6.0 | p = 0.046 |
| n (%) PSQI score >5 | 14/18 (77.8%) | 11/20 (55.0%) | 25/38 (65.8%) | 8/14 (57.1%) | 10/27 (37.0%) | 18/41 (43.9%) | RR = 1.50 (0.99, 2.27)<br>p = 0.075 |
| ESS, mean | 7.2 | 8.4 | 7.8 | 6.4 | 5.3 | 5.7 | p = 0.032 |
| n (%) ESS score >10 | 3/18 (16.7%) | 6/20 (30.0%) | 9/38 (23.7%) | 2/14 (14.3%) | 2/27 (7.4%) | 4/41 (9.8%) | RR = 2.43 (0.81, 7.23)<br>p = 0.131 |
| Mean worse sleep post turbines score (1–5 scale) | 3.2 | 3.1 | 3.1 | 1.2 | 1.4 | 1.3 | p <0.0001 |
| n (%) improved sleep away from turbines | 9/14 (64.3%) | 5/14 (35.7%) | 14/28 (50.0%) | 1/11 (9.1%) | 1/23 (4.3%) | 2/34 (5.9%) | RR = 8.5 (2.11, 34.3)<br>p <0.0001 |
| n (%) new sleep medications post turbines | 2/18 (11.1%) | 3/20 (15.0%) | 5/38 (13.2%) | 1/14 (7.1%) | 2/27 (7.4%) | 3/41 (7.3%) | RR = 1.80 (0.46, 7.02)<br>p = 0.47 |
| n (%) new diagnosis of insomnia | | | 2/38 (5.3%) | | | 0/41 (0%) | RR not calculable<br>p = 0.23 |
| n (%) new diagnosis of depression or anxiety | | | 9/38 (23.7%) | | | 0/41 (0%) | RR not calculable<br>p = 0.001 |
| n (%) prescribed new psychotropic medications post turbines | | | 9/38 (23.7%) | | | 3/41 (7.3%) | RR = 3.24 (0.94, 11.1)<br>p = 0.06 |
| SF-36 MCS[a], mean | 40.7 | 43.1 | 42.0 | 50.7 | 54.1 | 52.9 | p = 0.002 |
| SF-36 PCS[b], mean | NR | | | NR | | | no difference, p = 0.99 |
| n (%) wishing to move away post turbines | 14/18 (77.8%) | 14/20 (70.0%) | 28/38 (73.7%) | 0/14 (0%) | 0/27 (0%) | 0/41 (0%) | RR not calculable<br>p <0.0001 |

| | **Public health importance (1–4) [26]** | | **Relevance (1–5) [27]** |
|---|---|---|---|
| [a] Mental component score<br>[b] Physical component score | PSQI score | 2 | 1 |
| | ESS score | 2 | |
| | Improved sleep away from turbine | 1 | |
| | New sleep medication | 2 | |
| | New medication (psychotropic) | 2 | |

**Comments [28]**

Although there were statistically significant differences in the mean scores for the 2 sleep questionnaires and the mental health component of the SF-36 questionnaire, there was no statistically significant difference in the overall number of people affected between the near and far groups. The cross-sectional design of the study and the way it has been executed/analysed means that there is a high risk of recall bias, sample selection bias, confounding, statistically significant associations occurring due to chance and exposure misclassification. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.

## New Zealand study

**ARTICLE DETAILS**

**Reference [1]**

**Shepherd**, D, McBride, D, Welch, D, Dirks, KN & Hill, EM **2011**, 'Evaluating the impact of wind turbine noise on health-related quality of life', *Noise & Health*, vol. 13, no. 54, pp. 333–339.

**Affiliation/source of funds [2]**

Auckland University of Technology, New Zealand, University of Otago, New Zealand, and The University of Auckland, New Zealand.

| Study design [3] | Level of evidence [4] | Location/setting [5] |
|---|---|---|
| Cross-sectional | IV | Makara Valley, New Zealand; hilly terrain with long ridges 250–450 m above sea level.<br>**Proximity/distance:**<br>Exposed participants in dwellings (n=56 homes) <2 km from the nearest wind turbine; non-exposed controls resided (n=250 homes) ≥8 km from a turbine. |

| Exposure description [6] | Control(s) description [8] |
|---|---|
| **Wind farm details:**<br>66 turbines (Siemens SWT-2.3-82 VS)<br>Turbine height = 125 m<br>Rotor diameter = 82 m<br>**Specific exposure details:**<br>Typical noise exposure range = 24–54 dB(A).<br>**Sample size [7]**<br>Each household received 2 questionnaires, generating a sample of ≈112, with 39 respondents and response rate = 34% (sample is approximate because only individuals aged >18 years could respond). | Socioeconomic and geographic matched sample differing from the exposure group only by distance from wind turbines (≥8 km).<br>**Sample size [9]**<br>≈500, with 158 respondents and response rate = 32% (further details as per exposed group sample size). |

**Population characteristics [10]**

| | Exposure group (near), n=39 | | Control group (far), n=158 | |
|---|---|---|---|---|
| *Variables* | n | (%) | n | (%) |
| Sex, n (%) male | 16 | (41) | 63 | (41) |
| Age group, years | | | | |
| 18–20 | 1 | (2.6) | 2 | (1.2) |
| 21–30 | 1 | (2.6) | 1 | (0.5) |
| 31–40 | 5 | (12.8) | 22 | (13.9) |
| 41–50 | 10 | (25.6) | 53 | (33.5) |
| 51–60 | 11 | (28.2) | 44 | (27.8) |

| | | | | |
|---|---|---|---|---|
| 61–70 | 7 | (17.9) | 27 | (17.1) |
| ≥71 | 3 | (7.7) | 9 | (5.6) |
| Education (completed) | | | | |
| High school | 11 | (28.2) | 55 | (34.8) |
| Polytechnic | 11 | (28.2) | 48 | (30.3) |
| University | 17 | (43.6) | 54 | (34.2) |
| Employment status | | | | |
| Full time | 21 | (53.8) | 83 | (52.5) |
| Part time | 0 | (0) | 3 | (1.8) |
| Unpaid work | 1 | (2.6) | 3 | (1.8) |
| Unemployed | 6 | (15.3) | 27 | (17.1) |
| Retired | 10 | (25.6) | 40 | (25.3) |
| Noise sensitivity | | | | |
| None | 13 | (33.3) | 60 | (37.9) |
| Moderate | 21 | (55.3) | 76 | (48.1) |
| Severe | 5 | (12.8) | 20 | (12.7) |
| Current illness | | | | |
| Yes | 10 | (27) | 50 | (31.6) |
| No | 27 | (69.2) | 104 | (65.8) |

**Length of follow-up [11]**

NA (cross-sectional study).

**Outcome(s) measured and/or analyses undertaken [12]**

Quality of life as determined by self-administered brief version of the World Health Organization (WHO) quality of life (WHOQOL-BREF) scale (26 items) [validated], plus additional questions on amenity (2 items), neighbourhood problems (14 items), annoyance (7 items), demographic information (7 items) and a single item probing noise sensitivity.

**INTERNAL VALIDITY**

**Confounding subscale [13]**

***Comment on sources of confounding:***
Unequal distribution of some baseline characteristics between 'near' and 'far' groups, although not statistically significant. Socioeconomic and geographic matching undertaken and adjustment by length of residence. Unclear whether there was any clustering effect of responses as two questionnaires delivered to each household. Other plausible confounders not addressed ie age, education, chronic disease and risk factors for chronic disease, occupation, employment, background noise, and turbine visibility.

**Bias subscale [14]**

***Comment on sources of bias:***

**EXTERNAL VALIDITY**

**Generalisability [15]**

Survey sample members were either within 2 km of a turbine (exposed) or more than 8 km from a turbine (non-exposed); potential for differences between the total population living near the included wind farms and those that responded to questionnaire.

**Applicability [16]**

Unknown whether the population characteristics and the wind turbine exposures of those living near wind farms in New Zealand are comparable to those living near wind farms in Australia.

Very poor response rate for both turbine and comparison groups, and it is unclear whether self-selection could have introduced any selection bias in terms of important differences between the two groups—although study intent was masked.

**Reporting subscale [17]**

***Comment on quality of reporting:***
Good.

**Chance [18]**

Statistical adjustments for undertaking multiple statistical tests were reported (Bonferroni correction).

**Overall quality assessment (descriptive) [19]**

On the basis of the Internal Validity assessment made above, and the detailed critical appraisal of the study given in Table 7, this study is considered poor quality for the purpose of this review.

There is a high risk of exposure misclassification (time criterion was not well-defined), sample selection bias (~34% response rate), and confounding. There is also the potential for outcome misclassification (some non-validated survey questions) and recall bias (unclear if masking of study intent was effective).

## RESULTS

**Adverse effect outcomes [20]**

*Pearson product-moment correlation coefficients (r) for noise-related and QoL variables. Statistics to the right of the major diagonal are for the control group, while those to the left are for the exposure group.*

| | | | | | QoL | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Sensitivity | Annoyance | Sleep | Health | Physical | Psychological | Social | Environment | Overall |
| Sensitivity | 1 | 0.134 | –0.017 | 0.082 | –0.017 | –0.069 | 0.006 | –0.666 | –0.109 |
| Annoyance | 0.440[b] | 1 | 0.042 | –0.258[b] | –0.209[a] | –0.135 | –0.155[a] | –0.319[b] | –0.097 |
| Sleep | –0.433[b] | –0.147 | 1 | 0.337[b] | 0.378[b] | 0.489[b] | 0.327[b] | 0.279[b] | 0.198[a] |
| Health | –0.234 | –0.308 | 0.471[b] | 1 | 0.706[b] | 0.493[b] | 0.158[b] | 0.284[b] | 0.327[b] |
| Physical | –0.24 | –0.212 | 0.364[a] | 0.524[b] | 1 | 0.655[b] | 0.29[b] | 0.455[b] | 0.475[b] |
| Psychological | –0.404 | –0.113 | 0.473[b] | 0.329[a] | 0.268 | 1 | 0.55[b] | 0.608[b] | 0.589[b] |
| Social | –0.359 | –0.236 | 0.116 | –0.021 | 0.036 | 0.212 | 1 | 0.456[b] | 0.45[b] |
| Environment | –0.235 | 0.028 | 0.404[b] | 0.200 | 0.474 | 0.468[a] | –0.17 | 1 | 0.546[b] |
| Overall | –0.203 | 0.160 | 0.471[b] | 0.289 | 0.282 | 0.286 | 0.162 | 0.380[a] | 1 |

QoL = quality of life

[a] p<0.05
[b] p<0.001
[c] Questionnaire item 16 (satisfaction with sleep) was removed from the Physical QoL domain when correlated with sleep satisfaction

*Mean statistics for the four QoL domains of the WHOQOL-BREF total scores.*

| Measure, mean±SD | Exposure group | Control group | p value, between-group difference |
|---|---|---|---|
| Physical | 27.38±3.14 | 29.14±3.89 | 0.017 |
| Psychological | 22.36±2.67 | 23.29±2.91 | 0.069 |
| Social | 12.53±1.83 | 12.54±2.13 | 0.963 |
| Environmental | 29.92±3.76 | 32.76±4.41 | 0.018 |
| Amenity | 7.46±1.42 | 8.91±2.64 | <0.001 |

QoL=quality of life, SD=standard deviation

Physical domain: maximum score of 35; psychological domain: maximum score of 30; social domain: maximum score of 15; environmental domain: maximum score of 40. Amenity domain was added to the questionnaire by the authors.

| Exposure group [21] | Control group [22] | Measure of effect / effect size [23] 95% CI [25] | Harms (NNH) [24] 95% CI [25] |
|---|---|---|---|
| See 'Adverse effect outcomes' [20]. | See 'Adverse effect outcomes' [20]. | See [20]. | See [20]. |

| Public health importance (1–4) [26] | Relevance (1–5) [27] |
|---|---|
| Physical QoL: rank of 4<br>Psychological QoL: rank of 4<br>Social QoL: rank of 4 | 1 |

**Comments [28]**

This study was cross-sectional in design. This does not permit any conclusions regarding causation between health outcomes and noise exposure from turbines; that is, it is unknown whether the self-reported health outcomes occurred prior to or after exposure. Even though important QoL endpoints were selected, the differences between groups are small and potentially attributable to factors other than wind turbine exposure, given the lack of adjustment for other plausible confounders.

The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.

# SWE-00 study

| ARTICLE DETAILS | | |
|---|---|---|
| **Reference [1]**<br>**Pedersen**, E & Persson Waye, KP **2004**, 'Perception and annoyance due to wind turbine noise: a dose–response relationship', *Journal of the Acoustical Society of America*, vol. 116, no. 6, pp. 3460–3470. | | |
| **Affiliation/source of funds [2]**<br>Department of Environmental Medicine, Göteborg University, Göteborg, Sweden.<br>Funded through grant P13644-1 from the Swedish Energy Agency and Adlerberska Research Foundation. | | |
| **Study design [3]**<br>Cross-sectional study | **Level of evidence [4]**<br>IV | **Location/setting [5]**<br>Five areas within a 22-km$^2$ region of southern Sweden.<br>Landscape predominantly flat and mainly agricultural, but with small industries, roads and railroads present.<br>**Proximity/distance:** Distance from dwelling of respondent to nearest turbine, range = 150–1199 m |

| Exposure description [6] | Control(s) description [8] |
|---|---|
| **Wind farm details:**<br>14 towers within the study areas had a power output of 600–650 kW, 2 towers had outputs of 500 kW and 150 kW.<br>Tower height, range = 47–50 m.<br>Turbine make: 13 WindWorld, 2 Enercon, 1 Vestas.<br>**Specific exposure details:**<br>A-weighted (dB(A)) sound pressure levels due to turbines were estimated based on sound propagation models and calculated for each respondent's dwelling, grouped by 6 categories: <30.0, 30.0–32.5, 32.5–35.0, 35.0–37.5, 37.5–40.0 and >40.0 dB(A).<br>**Sample size [7]**<br>Total = 513; respondents, n=351; non-respondents, n=162; response rate 68%. | No non-exposed groups were included in the study. Responder characteristics across different types of environmental exposure were reported (see 'Specific exposure details').<br>**Sample size [9]**<br>See 'Population characteristics'. |

| Population characteristics [10] |
|---|
| **Exposure group:** |

| | Estimated A-weighted sound pressure intervals in dB(A)[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | <30.0 | 30.0–32.5 | 32.5–35.0 | 35.0–37.5 | 37.5–40.0 | >40.0 | Total |
| Study sample, n | 25 | 103 | 200 | 100 | 53 | 32 | 513 |
| Respondents, n | 15 | 71 | 137 | 63 | 40 | 25 | 351 |
| Response rate, % | 60 | 68.9 | 68.5 | 63 | 75.5 | 78.1 | 68.4 |
| Age, mean±SD | 46±13.3 | 47±13.3 | 47±14.3 | 50±14.6 | 48±13.1 | 48±14.3 | 48±14.0 |
| Sex, % male | 27 | 35 | 39 | 50 | 50 | 48 | 42 |
| Residence, detached house/farm % | 100 | 83 | 61 | 100 | 97 | 96 | 81 |
| Occupation, % employed | 67 | 59 | 58 | 53 | 69 | 67 | 60 |
| Sensitive to noise, % | 62 | 44 | 49 | 53 | 58 | 50 | 50 |
| Negative toward turbines, % | 8 | 10 | 11 | 18 | 20 | 8 | 13 |
| Negative to turbine visual impact, % | 43 | 33 | 38 | 41 | 40 | 58 | 40 |
| Long term illness, % | 20 | 29 | 28 | 16 | 30 | 24 | 26 |

[a] These are the intervals as reported by the authors. Note that the intervals are not mutually exclusive. For further details regarding the utility/relevance of results included in this paper, see 'Outcomes measured'.
Abbreviations: SD = standard deviation

**Length of follow-up [11]**

NA (cross-sectional study)

**Outcome(s) measured and/or analyses undertaken [12]**

Perception and annoyance due to wind turbine sound across the nominated estimated sound categories. Influence of subjective factors on annoyance (visual impact, attitude to turbines, noise sensitivity). Correlations between turbine noise annoyance, sound category and subjective variables (as above). Correlations between noise annoyance and verbal descriptors of noise (swishing, whistling, pulsating/ throbbing, resounding, low frequency, scratching/squeaking, tonal, and lapping).

**INTERNAL VALIDITY**

**Confounding subscale [13]**

***Comment on sources of confounding:***
Analyses adjusted for some sources of confounding (age, gender, noise sensitivity, visual impact, attitude to turbines – covariates varied across analyses) but other plausible confounders not addressed i.e. socioeconomic status, economic factors, chronic disease and risk factors for chronic disease, occupation, education, employment, terrain,

**EXTERNAL VALIDITY**

**Generalisability [15]**

Survey delivered to a sample of households within ~1.2 km of wind turbines; potential for differences between the total population living near the included wind farms and those that responded to questionnaire.

**Applicability [16]**

Uncertain whether the population characteristics and

| | |
|---|---|
| urbanisation and background noise.<br><br>**Bias subscale [14]**<br><br>***Comment on sources of bias:***<br>Individuals experiencing more annoyance would have a higher tendency to fill in or return a questionnaire; therefore, potential for sample selection bias. 32% of people who received a survey did not respond. Masking of study intent was attempted but it is unknown whether it was successful (recall bias). | the wind turbine exposures of those living near selected Swedish wind farms are applicable to populations near wind farms in Australia. |

**Reporting subscale [17]**

***Comment on quality of reporting:*** Good reporting of responder demographics according to sound exposure groups, although the characteristics of non-responders were not reported. The study did not report on economic benefits from wind turbines.

**Chance [18]**

Bonferroni corrections were used to reduce the possibility of spurious significant associations arising by chance as multiple statistical tests were conducted.

**Overall quality assessment (descriptive) [19]**

On the basis of the Internal Validity assessment made above, the lack of reporting of health outcomes, and the detailed critical appraisal of the study (see Table 7), this study is considered poor quality for the purpose of this review.

There is a high risk of exposure misclassification (time criterion was not well-defined), uncertain sample selection bias (68% response rate), outcome misclassification (non-validated survey) and confounding. There is also the potential for recall bias (unclear if masking of study intent was effective).

## RESULTS

**Adverse effect outcomes [20]**

*Perception and annoyance outdoors (%) from wind turbine noise related to sound exposure.*

Estimated sound pressure intervals in dB(A)

| | <30.0<br>n=12 | 30.0–32.5<br>n=70 | 32.5–35.0<br>n=132 | 35.0–37.5<br>n=62 | 37.5–40.0<br>n=40 | >40.0<br>n=25 |
|---|---|---|---|---|---|---|
| Do not notice | 75 [51,100] | 61 [50,73] | 38 [30,46] | 15 [3,23] | 15 [4,26] | 4 [19,57] |
| Notice, not annoyed | 25 [1,50] | 24 [14,34] | 28 [20,36] | 47 [34,59] | 35 [20,50] | 40 [19,57] |
| Slightly annoyed | 0 | 14 [6,22] | 17 [10,23] | 26 [15,37] | 23 [10,35] | 12 [19,57] |
| Rather annoyed | 0 | 0 | 10 [5,15] | 6 [0,13] | 8 [–1,16][a] | 8 [19,57] |
| Very annoyed | 0 | 0 | 8 [3,12] | 6 [0,13] | 20 [8,32] | 36 [17,55] |

Note: Values are % [95% CI] unless otherwise specified.
[a] Reproduced as per reported in study. This is evidently in error, as a negative percentage is not possible. The interval could plausibly be [1,16].

*Results of multiple logistic regression analyses—impact of predictors on annoyance.*

| | Variables | *b* | p value | Exp*(b)* [95% CI] | Pseudo-$R^2$ |
|---|---|---|---|---|---|
| 1 | Noise exposure | 0.63 | <0.001 | 1.87 [1.47,2.38] | 0.13 |

| | | | | |
|---|---|---|---|---|
| 2 Noise exposure | 0.55 | <0.001 | 1.74 [1.29,2.34] | 0.46 |
| Attitude to visual impact | 1.62 | <0.001 | 5.05 [3.22,7.92] | NR |
| 3 Noise exposure | 0.62 | <0.001 | 1.86 [1.45,2.40] | 0.20 |
| Attitude to turbines | 0.56 | <0.001 | 1.74 [1.30,2.33] | NR |
| 4 Noise exposure | 0.63 | <0.001 | 1.88 [1.46,2.42] | 0.18 |
| Sensitivity to noise | 0.56 | <0.001 | 1.75 [1.19,2.57] | NR |
| 5 Noise exposure | 0.55 | <0.001 | 1.73 [1.28,2.33] | 0.46 |
| Attitude to visual impact | 1.66 | <0.001 | 5.28 [3.26,8.56] | NR |
| Attitude to turbines | –0.10 | 0.319 | 0.91 [0.64,1.28] | NR |
| 6 Noise exposure | 0.57 | <0.001 | 1.77 [1.30,2.40] | 0.47 |
| Attitude to visual impact | 1.59 | <0.001 | 4.88 [3.08,7.72] | NR |
| Sensitivity to noise | 0.22 | 0.344 | 1.25 [0.79,1.96] | NR |
| 7 Noise exposure | 0.63 | <0.001 | 1.88 [1.45,2.45] | 0.24 |
| Attitude to turbines | 0.58 | <0.001 | 1.78 [1.32,2.41] | NR |
| Sensitivity to noise | 0.59 | <0.005 | 1.80 [1.22,2.67] | NR |
| 8 Noise exposure | 0.56 | <0.001 | 1.76 [1.29,2.39] | 0.47 |
| Attitude to visual impact | 1.63 | <0.001 | 5.11 [3.10,8.41] | NR |
| Attitude to turbines | –0.10 | 0.597 | 0.91 [0.64,1.29] | NR |
| Sensitivity to noise | 0.21 | 0.373 | 1.23 [0.78,1.94] | NR |

*Correlations between noise annoyance, estimated sound category (dB(A)) and subjective variables*

| | Sound category | Attitude to visual impact | Attitude to turbines | Sensitivity to noise |
|---|---|---|---|---|
| Noise annoyance | **0.421** | **0.512** | **0.334** | **0.197** |
| Sound category | NA | **0.145** | 0.074 | 0.069 |
| Attitude to visual impact | NR | NA | **0.568** | **0.194** |
| Attitude to turbines | NR | NR | NA | 0.023 |
| Sensitivity to noise | NR | NR | NR | NA |

**Bold text indicates statistically significant.**

*Verbal descriptors of sound characteristics of turbine noise for those that noticed turbine sound* (n=223)

| | Annoyed by specified sound character, % respondents [95% CI] | Correlation to noise annoyance |
|---|---|---|
| Swishing | 33 [27,40] | **0.718** |
| Whistling | 26 [18,33] | **0.642** |
| Pulsating/throbbing | 20 [14,27] | **0.450** |
| Resounding | 16 [10,23] | **0.485** |
| Low frequency | 13 [7,18] | **0.292** |
| Scratching/squeaking | 12 [6,17] | **0.398** |
| Tonal | 7 [3,12] | **0.335** |
| Lapping | 5 [1,8] | **0.262** |

**Bold text indicates statistically significant.**
Abbreviations: NR = not reported; NA = not applicable

<table>
<tr><td colspan="2">Exposure group [21]<br>See ‘Adverse effect outcomes’ [20].</td><td colspan="2">Control group [22]<br>NA</td><td colspan="2">Measure of effect / effect size [23]<br>95% CI [25]<br>See [20].</td><td colspan="2">Harms (NNH) [24]<br>95% CI [25]<br>NR—health outcomes not reported.</td></tr>
<tr><td colspan="4">Public health importance (1–4) [26]<br>Unable to determine according to NHMRC ranking criteria.</td><td colspan="4">Relevance (1–5) [27]<br>5</td></tr>
<tr><td colspan="8">Comments [28]<br>The cross-sectional study design cannot provide evidence of cause and effect, and, although exploration of potential sources of confounding was done, there were some potential confounders that were not addressed. Results may be affected by recall bias, although attempts were made to mask study intent. Health outcomes were not reported. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.</td></tr>
</table>

# SWE-05 study

## ARTICLE DETAILS

**Reference [1]**

**Pedersen**, E & Persson Waye, K **2007**, 'Wind turbine noise, annoyance and self-reported health and well-being in different living environments', *Occupational and Environmental Medicine*, vol. 64, no. 7, pp. 480–486.

**Affiliation/source of funds [2]**

Occupational and Environmental Medicine, Sahlgrenska Academy, Göteborg University, Göteborg, Sweden.

Funded through grant P2005-04699 by the Swedish Energy Agency.

| Study design [3] | Level of evidence [4] | Location/setting [5] |
|---|---|---|
| Cross-sectional study. | IV | Seven wind turbine areas in Sweden representing different landscapes with regard to terrain and urbanisation.<br><br>**Proximity/distance:**<br>Mean, 780±233 m |

**Exposure description [6]**

**Wind farm details:**
Wind turbines with nominal power >500 kW (authors reported that some turbines with nominal power <500 kW were included for analysis).

Tower height >65 m.

**Specific exposure details:**
Sound pressure levels (SPL) collected from reports by consultancies, manufacturers and local authorities, or, where data were unavailable, older/smaller machines. Noise emission was estimated outside each respondent's residence. The standard model of sound propagation proposed by the Swedish Environmental Protection Agency was used to estimate A-weighted SPL in decibels (dB), based on downwind conditions (±45°) with wind speed 8 m/s at height 10 m. SPL divided into 5 categories: <32.5, 32.5–35.0, 35.0–37.5, 37.5–40.0 and >40.0 dB(A).

Turbine area types included Areas I–IV where ground was rocky and/or the altitude of the base of the wind turbines varied; and Areas V–VII, which were flat. Areas I, IV and VII were classified as suburban, Areas II, III, V and VI as rural.

**Sample size [7]**

**Control(s) description [8]**

No non-exposed groups were included in the study.

A distribution of participant characteristics across different environmental exposures was included (see 'Specific exposure details'); however, these classifications do not coincide with the different sound pressure levels considered and no analysis based on these subgroups was presented.

**Sample size [9]**

See 'Population characteristics'.

Respondents, n=754; non-respondents, n=555; response rate = 58%.

**Population characteristics [10]**

**Exposure group:**

| | I | II | III | IV | V | VI | VII | Total |
|---|---|---|---|---|---|---|---|---|
| Sample, n | 396 | 24 | 23 | 221 | 148 | 112 | 385 | 1309 |
| Respondents, n | 206 | 16 | 12 | 141 | 87 | 70 | 222 | 754 |
| Age, years | 52±15 | 51±18 | 54±15 | 52±14 | 49±16 | 49±15 | 51±15 | 51±15 |
| Sex, % male | 40 | 53 | 58 | 47 | 48 | 38 | 46 | 44 |
| Occupation, | | | | | | | | |
| % employed | 54 | 33 | 58 | 57 | 61 | 58 | 62 | 58 |
| % retired | 28 | 53 | 33 | 24 | 22 | 21 | 23 | 25 |
| Housing type, | | | | | | | | |
| % detached | 70 | 93 | 100 | 70 | 89 | 93 | 82 | 79 |
| Time in current dwelling, years | 14±14 | 16±10 | 16±15 | 15±13 | 15±15 | 15±16 | 16±12 | 15±13 |
| Distance to nearest turbine, m | 862±184 | 636±254 | 670±284 | 812±151 | 834±266 | 1014±245 | 605±160 | 780±233 |
| Sound pressure level, dB(A) | 31.4±2.3 | 38.2±4.7 | 33.8±4.5 | 33.2±1.4 | 34.6±3.2 | 31.9±2.3 | 35.0±2.9 | 33.4±3.0 |
| Visual angle, degrees | 3.5±0.9 | 10.8±3.9 | 8.4±4.3 | 2.5±0.4 | 2.7±1.3 | 3.6±1.7 | 3.8±0.8 | 3.5±1.7 |
| Respondents with ≥1 turbine visible, % | 64 | 75 | 67 | 60 | 91 | 88 | 71 | 71 |
| Respondents noise sensitive, % | 54 | 50 | 42 | 59 | 39 | 56 | 48 | 51 |
| Self-rated health, % chronic disease | 36 | 33 | 67 | 35 | 21 | 26 | 32 | 33 |
| Self-rated sleep, % not good | 9 | 0 | 0 | 6 | 5 | 4 | 5 | 6 |

Values are mean±SD unless otherwise indicated

**Length of follow-up [11]**

NA (cross-sectional design).

**Outcome(s) measured and/or analyses undertaken [12]**

No data from the subgroup analysis based on different categories of noise levels could be extracted; however, a later study (Pedersen 2011) contains data on relevant endpoints for the same study population considered here.

The outcomes reported in this study were: perception of noise and annoyance with noise.

| INTERNAL VALIDITY | EXTERNAL VALIDITY |
|---|---|
| **Confounding subscale [13]**<br>***Comment on sources of confounding:***<br>Analysis adjusted for age and sex and multiple other factors (see 'Results') but it is unknown if confounding due to economic benefit occurred. Findings could be partly due to differences between rural and urban areas in terms of background noise, which is not an exposure of interest. Other plausible confounders not addressed were: chronic disease and risk factors for chronic disease, occupation and education.<br>**Bias subscale [14]**<br>***Comment on sources of bias:***<br>Study intent was masked, but unclear how effectively and so whether recall bias has affected results. | **Generalisability [15]**<br>Overall mean distance from wind turbines ~800 m; potential for differences between the total population living near the included wind farms and those that responded to questionnaire (58% response rate).<br>**Applicability [16]**<br>Uncertain whether the population characteristics and the wind turbine exposures of those living near Swedish wind farms are comparable to populations near wind farms in Australia. |

**Reporting subscale [17]**

***Comment on quality of reporting:***
Good reporting of responder demographics according to sound exposure groups, although baseline health was not considered (cross-sectional design), nor the characteristics of non-responders. The study did not report on economic benefits from wind turbines.

**Chance [18]**

There was the possibility of spurious significant associations because of the multiple statistical analyses undertaken.

**Overall quality assessment (descriptive) [19]**

There was good reporting of study characteristics and adjustment for potential confounders, and attempts to reduce recall bias through masking study intent. There are still concerns regarding plausible confounders not being controlled. Health outcomes were not reported. There was the possibility of spurious significant associations with annoyance because of the multiple statistical analyses undertaken. Unclear whether there is sample selection bias, given the moderate response rate. High risk of outcome misclassification as the survey tool was not validated. The study was of poor quality for the purpose of this review.

For further critical appraisal of the study, see Table 7.

## RESULTS

**Adverse effect outcomes [20]**

*Association between perception of noise from wind turbines, dependent variable 'Do not notice' (n=457) or 'Notice' (n=307) and variables hypothesised to influence perception.*

| Sound pressure, dB(A) | Other variables hypothesised to influence perception<br>Variable of interest (ref; tested category)[a] | OR [95% CI] |
|---|---|---|
| 1.3 [1.26,1.41] | Age (years; +1 year) | 1.0 [0.99,1.01] |

| | | |
|---|---|---|
| 1.3 [1.26,1.41] | Sex (male; female) | 1.0 [0.83,1.16] |
| 1.3 [1.26,1.41] | Employment (employed; not employed) | 0.7 [0.48,0.91] |
| 1.3 [1.26,1.41] | Housing (apartment; detached house) | 1.6 [1.04,2.33] |
| 1.3 [1.24,1.40] | Terrain (complex; flat) | 1.1 [0.81,1.56] |
| 1.3[1.25,1.41] | Urbanisation (suburban; rural) | 1.8 [1.25,2.51] |
| 1.3 [1.24,1.41] | Terrain and urbanisation | |
| | Suburban & flat ground (n=222) | 1.0 |
| | Suburban & complex ground (n=347) | 1.0 [0.65,1.48] |
| | Rural & flat ground (n=157) | 1.6 [1.01,2.53] |
| | Rural & complex ground (n=28) | 4.8 [1.65,13.72] |
| 1.3 [1.22,1.38] | Subjective background noise (not quiet; quiet) | 1.8 [1.25,2.51] |
| 1.3 [1.22,1.37] | Visibility (no; yes) | 2.2 [1.47,3.18] |

| | |
|---|---|
| Model 1[bc] (Hosmer and Lemshow test: 0.703) | |
| Sound pressure level, dB(A) | 1.3 [1.21,1.39] |
| Employment (employed; not employed) | 0.6 [0.40,0.83] |
| Terrain (complex; flat) | 0.6 [0.38,0.97] |
| Urbanisation (suburban; rural) | 2.3 [1.34,3.88] |
| Subjective background noise (not quiet; quiet) | 2.6[1.72,3.95] |
| Visibility (no; yes) | 2.3 [1.51,3.47] |
| Model 2[bc] (Hosmer and Lemshow test: 0.703) | |
| Sound pressure level, dB(A) | 1.3 [1.21,1.39] |
| Employment (employed; not employed) | 0.6 [0.40,0.83] |
| Terrain and urbanisation | |
| Suburban & flat ground (n=222) | 1.0 |
| Suburban & complex ground (n=347) | 1.6 [1.03,2.63] |
| Rural & flat ground (n=157) | 2.2 [1.34,3.89] |
| Rural & complex ground (n=28) | 13.8 [4.24,45.15] |
| Subjective background noise (not quiet; quiet) | 2.6 [1.72,3.95] |
| Visibility (no; yes) | 2.3 [1.51,3.47] |

[a] Variables were entered one by one into a binary logistic regression, always keeping sound pressure level in the regression as the main factor of importance for perception.
[b] Models 1 and 2 comprise several variables simultaneously entered into a binary logistic regression.
[c] Adjusted for age and sex.

*Association between annoyance with noise from wind turbines, dependent variable 'Not annoyed' (n=723) or 'Annoyed' (n=31) and variables hypothesised to influence annoyance.*

| Sound pressure, dB(A) | Other variables hypothesised to influence annoyance<br>Variable of interest (ref; tested category)[a] | OR [95% CI] |
|---|---|---|
| 1.1 [1.03,1.27] | Age (years; +1 year) | 1.0 [0.99,1.04] |
| 1.1 [1.02,1.26] | Sex (male; female) | 0.9 [0.50,1.64] |
| 1.1 [1.01,1.25] | Employment (employed; not employed) | 1.3 [0.61,2.60] |
| 1.1 [1.01,1.25] | Housing (apartment; detached house) | 2.5 [0.75,8.40] |
| 1.1 [1.01,1.25] | Length of time in current dwelling (years; +1 year) | 1.0 [1.00,1.05] |
| 1.1 [1.02,1.26] | Terrain (complex; flat) | 0.8 [0.39,1.76] |
| 1.1 [0.99,1.21] | Urbanisation (suburban; rural) | 3.8 [1.80,7.83] |
| 1.1 [0.98,1.23] | Terrain and urbanisation | |
| | Suburban & flat ground (n=222) | 1.0 |
| | Suburban & complex ground (n=347) | 2.1 [0.63, 7.28] |
| | Rural & flat ground (n=157) | 5.2 [1.62, 16.65] |
| | Rural & complex ground (n=28) | 10.1 [2.46, 41.61] |
| 1.1 [0.91,1.21] | Subjective background noise (not quiet; quiet) | 3.6 [1.21, 10.67] |
| 1.1 [1.02,1.26] | Noise sensitivity (not sensitive; sensitive) | 2.5 [1.14,5.63] |

| | | |
|---|---|---|
| 1.1 [1.00,1.25] | General attitude to turbines (not negative; negative) | 13.4 [6.03,29.59] |
| 1.1 [1.00,1.25] | Attitude to visual impact of turbines (not negative; negative) | 14.4 [6.37,32.44] |
| 1.1 [1.01,1.25] | 'I live in a place where I can restore myself and gain strength' (disagree; agree) | 0.3 [0.13,0.74] |
| 1.1 [1.01,1.25] | 'I have renovated my dwelling' (no; yes) | 2.6 [1.03,6.33] |
| 1.0 [0.88,1.16] | Vertical visual angle (degrees; +1 degree) | 1.2 [1.03,1.42] |
| 1.1 [0.97,1.21] | Visibility (no; yes) | 10.9 [1.46,81.92] |

[a] Variables were entered one by one into a binary logistic regression, always keeping sound pressure level in the regression as the main factor of importance for perception.
Abbreviations: OR = odds ratio

| Exposure group [21] | Control group [22] | Measure of effect / effect size [23] 95% CI [25] | Harms (NNH) [24] 95% CI [25] |
|---|---|---|---|
| As per 'Adverse effect outcomes' [20]. | NA | See [20]. | Health effects were not reported. |

| Public health importance (1–4) [26] | Relevance (1–5) [27] |
|---|---|
| Cannot be determined according to NHMRC ranking criteria. | 5 |

**Comments [28]**

Health outcomes were not reported. Annoyance could lead to stress which is a potential mediating factor in adverse health but stress was not assessed. Cross-sectional design does not permit conclusions regarding cause and effect. Good attempt at controlling for confounding. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.

## SWE-00 vs SWE-05 study

### ARTICLE DETAILS

**Reference [1]**

**Pedersen**, E & Larsman, P **2008**, 'The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines', *Journal of Environmental Psychology*, vol. 28, no. 4, pp. 379–389.

**Affiliation/source of funds [2]**

Occupational and Environmental Medicine, Sahlgrenska Academy, Göteborg University, Sweden; Department of Psychology, Göteborg University, Sweden.

Funded through grant P22509-1 by the Swedish Energy Agency.

**Study design [3]**

Analysis based on two cross-sectional studies:

1. Pedersen, E & Persson Waye, KP 2004, 'Perception and annoyance due to wind turbine noise: a dose–response relationship', *Journal of the Acoustical Society of America*, vol. 116, no. 6, pp. 3460–3470.
2. Pedersen, E & Persson Waye, K 2007, 'Wind turbine noise, annoyance and self-reported health and well-being in different living environments', *Occupational and Environmental Medicine*, vol. 64, no. 7, pp. 480–486.

**Level of evidence [4]**

IV

**Location/setting [5]**

12 geographical areas in southern Sweden that differed with regard to terrain (flat or hilly/rocky) and degree of urbanisation (built-up or rural).

**Proximity/distance:**
Pedersen & Persson Waye (2004): Distance from dwelling of respondent to nearest turbine, range = 150–1199 m.

Pedersen & Persson Waye (2007): Mean, 780±233 m.

**Exposure description [6]**

**Wind farm details:**
*Pedersen & Persson Waye (2004)*
14 towers within the study areas had a power output of 600–650 kW, 2 towers had outputs of 500 kW and 150 kW.
Tower height, range = 47–50 m.
Turbine make: 13 WindWorld, 2 Enercon, 1 Vestas.

*Pedersen & Persson Waye (2007)*
Wind turbines with nominal power >500 kW (authors reported that some turbines with nominal power <500 kW were included for analysis).

**Specific exposure details:**
*Pedersen & Persson Waye (2004)*

**Control(s) description[8]**

No non-exposed groups were included in the study. Outcomes were measured across different types of environmental exposure (see 'Specific exposure details').

**Sample size [9]**

See 'Population characteristics'.

Estimated A-weighted (dB(A)) sound levels were based on sound propagation models calculating levels at each respondent's dwelling, and these levels were grouped into 6 categories as shown at 'Population characteristics'.

*Pedersen & Persson Waye (2007)*
Sound power levels collected from reports by consultancies, manufacturers and local authorities, or, where data were unavailable, older/smaller machines. Noise emission was measured outside each respondent's residence. The standard model of sound propagation proposed by the Swedish Environmental Protection Agency was used to estimate as equivalent continuous A-weighted sound pressure level in decibels (dB), based on downwind conditions (±45°) with wind speed 8 m/s at height 10 m.

Turbine area types included Areas I–IV, where ground was rocky and/or the altitude of the base of the wind turbines varied; and Areas V–VII, which were flat. Areas I, IV and VII were classified as suburban, Areas II, III, V and VI as rural.

**Sample size [7]**

*Pedersen & Persson Waye (2004)*
Total = 513; respondents, n=351; non-respondents, n=162; response rate 68%.

*Pedersen & Persson Waye (2007)*
Total = 1309; respondents, n=754; non-respondents, n=555; response rate 58%.

**Population characteristics [10]**

**Exposure group:**
In both individual studies, demographic characteristics were presented across different levels of sound pressure (Pedersen & Persson Waye 2004) and dwelling/topographic features (Pedersen & Persson Waye 2007). The results of Pedersen (2008) were not reported according to the categories of exposure examined in the individual studies.

*Pedersen & Persson Waye (2004)*

| | Estimated A-weighted sound pressure intervals in dB(A)[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | <30.0 | 30.0–32.5 | 32.5–35.0 | 35.0–37.5 | 37.5–40.0 | >40.0 | Total |
| Study sample, n | 25 | 103 | 200 | 100 | 53 | 32 | 513 |
| Study population, n | 15 | 71 | 137 | 63 | 40 | 25 | 351 |
| Response rate, % | 60 | 68.9 | 68.5 | 63 | 75.5 | 78.1 | 68.4 |
| Age, mean±SD, years | 46±13.3 | 47±13.3 | 47±14.3 | 50±14.6 | 48±13.1 | 48±14.3 | 48±14.0 |
| Sex, % male | 27 | 35 | 39 | 50 | 50 | 48 | 42 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Residence, detached house/farm % | 100 | 83 | 61 | 100 | 97 | 96 | 81 |
| Occupation, % employed | 67 | 59 | 58 | 53 | 69 | 67 | 60 |
| Sensitive to noise, % | 62 | 44 | 49 | 53 | 58 | 50 | 50 |
| Negative toward turbines, % | 8 | 10 | 11 | 18 | 20 | 8 | 13 |
| Negative to turbine visual impact, % | 43 | 33 | 38 | 41 | 40 | 58 | 40 |
| Long-term illness, % | 20 | 29 | 28 | 16 | 30 | 24 | 26 |

[a] These are the intervals as reported by the authors. Note that the intervals are not mutually exclusive. For further details regarding the utility/relevance of results included in this paper, see 'Outcomes measured'.
Abbreviations: SD = standard deviation

*Pedersen & Persson Waye (2007)*

| | I | II | III | IV | V | VI | VII | Total |
|---|---|---|---|---|---|---|---|---|
| Sample, n | 396 | 24 | 23 | 221 | 148 | 112 | 385 | 1309 |
| Respondents, n | 206 | 16 | 12 | 141 | 87 | 70 | 222 | 754 |
| Age, years | 52±15 | 51±18 | 54±15 | 52±14 | 49±16 | 49±15 | 51±15 | 51±15 |
| Sex, % male | 40 | 53 | 58 | 47 | 48 | 38 | 46 | 44 |
| Occupation, | | | | | | | | |
| % employed | 54 | 33 | 58 | 57 | 61 | 58 | 62 | 58 |
| % retired | 28 | 53 | 33 | 24 | 22 | 21 | 23 | 25 |
| Housing type, | | | | | | | | |
| % detached | 70 | 93 | 100 | 70 | 89 | 93 | 82 | 79 |
| Time in current dwelling, years | 14±14 | 16±10 | 16±15 | 15±13 | 15±15 | 15±16 | 16±12 | 15±13 |
| Distance to nearest turbine, m | 862±184 | 636±254 | 670±284 | 812±151 | 834±266 | 1014±245 | 605±160 | 780±233 |
| Sound pressure level, dB(A) | 31.4±2.3 | 38.2±4.7 | 33.8±4.5 | 33.2±1.4 | 34.6±3.2 | 31.9±2.3 | 35.0±2.9 | 33.4±3.0 |
| Visual angle, degrees | 3.5±0.9 | 10.8±3.9 | 8.4±4.3 | 2.5±0.4 | 2.7±1.3 | 3.6±1.7 | 3.8±0.8 | 3.5±1.7 |
| Respondents with ≥1 turbine visible, % | 64 | 75 | 67 | 60 | 91 | 88 | 71 | 71 |
| Respondents noise sensitive, % | 54 | 50 | 42 | 59 | 39 | 56 | 48 | 51 |
| Self-rated health, % chronic disease | 36 | 33 | 67 | 35 | 21 | 26 | 32 | 33 |
| Self-rated sleep, % not good | 9 | 0 | 0 | 6 | 5 | 4 | 5 | 6 |

Values are mean±SD unless otherwise indicated

**Length of follow-up [11]**

NA (cross-sectional study).

**Outcome(s) measured and/or analyses undertaken [12]**

Three constructs of annoyance (due to noise, visual

| | |
|---|---|
| | attitude and general attitude). No health outcomes measured. |
| **INTERNAL VALIDITY**<br><br>**Confounding subscale [13]**<br><br>***Comment on sources of confounding:***<br>Confounding is a risk as the possibility of different distributions of economic benefit among the sound exposure groups was not analysed.<br><br>**Bias subscale [14]**<br><br>***Comment on sources of bias:***<br>Recall bias cannot be excluded, although masking of study intent was attempted in both studies. | **EXTERNAL VALIDITY**<br><br>**Generalisability [15]**<br><br>For both studies (i.e. Pedersen and Persson Waye 2004, 2007), distance from wind turbines did not exceed 1.2 km; potential for differences between the total population living near the included wind farms and those that responded to questionnaire.<br><br>**Applicability [16]**<br><br>Uncertain whether the population characteristics and the wind turbine exposures of those living near selected Swedish wind farms are comparable to populations near wind farms in Australia. |

**Reporting subscale [17]**

***Comment on quality of reporting:***
Poor reporting of participant characteristics and background data for non-respondents was not provided. The demographic data provided in this table have been extracted from the studies detailed above, which form the basis of the re-analysis of data in Pedersen (2008).

**Chance [18]**

This study is a re-analysis of the original studies conducted by Pedersen and Persson Waye as published in 2004 and 2007, and it is possible that spurious significant associations arose because of the multiple statistical analyses undertaken.

**Overall quality assessment (descriptive) [19]**

For further critical appraisal of the study, see Table 7.

Detailed discussion of selection process. There is a high risk of exposure misclassification (time criterion was not well-defined), outcome misclassification (non-validated surveys), confounding and statistically significant associations arising by chance. There is also the potential for recall bias (unclear if masking of study intent was effective) and an uncertain risk of sample selection bias.

## RESULTS

**Adverse effect outcomes [20]**

| Regression weights | Exposure groups | | | | Difference between groups[a] | |
|---|---|---|---|---|---|---|
| | Estimate | p value | Estimate | p value | Difference | p value |
| | At least one turbine visible group | | No turbines visible group | | | |
| Noise level → noise annoyance | 0.35 | <0.001 | 0.29 | <0.01 | 0.06 | <0.001 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Visual attitude → noise annoyance | 0.59 | <0.001 | 0.57 | <0.05 | 0.32 | <0.05 |
| General attitude → noise annoyance | –0.06 | 0.375 | –0.35 | 0.169 | NR | NR |
| | **Flat terrain** | | **Rocky terrain** | | | |
| Noise level → noise annoyance | 0.32 | <0.001 | 0.29 | <0.001 | –0.02 | 0.201 |
| Visual attitude → noise annoyance | 0.71 | <0.001 | 0.57 | 0.445 | NR | NR |
| General attitude → noise annoyance | –0.16 | 0.058 | –0.35 | 0.191 | NR | NR |
| | **Built-up area** | | **Rural area** | | | |
| Noise level → noise annoyance | 0.42 | <0.001 | 0.35 | <0.001 | 0.01 | 0.418 |
| Visual attitude → noise annoyance | 0.58 | <0.001 | 0.57 | <0.001 | –0.03 | 0.873 |
| General attitude → noise annoyance | –0.15 | 0.076 | –0.02 | 0.867 | NR | NR |

[a] Only calculated if the estimates were statistically significant.

Annoyance due to noise:

- Flat *vs* rocky terrain: noise levels had an effect on annoyance both for respondents living in both flat terrain and hilly/rocky terrain.
- Built-up *vs* rural area: noise levels had an effect on annoyance both for respondents living in both built-up areas and rural areas.
- Visibility of wind turbines from dwelling *vs* non-visibility: noise levels had an effect on annoyance for both groups, but the level of annoyance appeared stronger for the 'visibility of wind turbines' group.

*Regression coefficients from multiple linear regressions with the dependent variable 'response to wind turbine noise'.*

| | **A-weighted sound pressure level** *B* [95% CI] $R^2$ | **Revised vertical visual angle** *B* [95%CI] |
|---|---|---|
| Wing turbines visible | 0.12 [0.099,0.143] 0.04 | 0.01 [0.009,0.020] |
| Turbines not visible | 0.06 [0.001,0.025] 0.14 | 0.00 [–0.002,0.008] |
| Flat terrain | 0.13 [0.102,0.152] 0.15 | 0.03 [0.023,0.040] |
| Hilly/rocky terrain | 0.13 [0.104,0.161] 0.20 | 0.00 [–0.001,0.008] |
| Built-up area | 0.13 [0.103,0.150] 0.14 | 0.00 [–0.007,0.013] |
| Rural area | 0.11 [0.078,0.145] 0.14 | 0.01 [0.003,0.016] |

<table>
<tr><td>Exposure group [21]<br>See ‘Adverse effect outcomes [20].</td><td>Control group [22]<br>NA</td><td>Measure of effect / effect size [23]<br>95% CI [25]<br>See [20].</td><td>Harms (NNH) [24]<br>95% CI [25]<br>Health effects not reported.</td></tr>
<tr><td colspan="2">Public health importance (1–4) [26]<br>Cannot be determined according to NHMRC ranking criteria.</td><td colspan="2">Relevance (1–5) [27]<br>5</td></tr>
<tr><td colspan="4">Comments [28]<br>Cross-sectional design cannot provide evidence of cause and effect. Health outcomes were not measured. The effects of visual and attitude factors on annoyance were considered; however, whether annoyance leads to adverse health outcomes has not been established. Economic benefit from wind turbines may influence annoyance, but this was not investigated. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.</td></tr>
</table>

## NL-07 vs SWE-00 vs SWE-05 study

**ARTICLE DETAILS**

**Reference [1]**

**Pedersen**, E **2011**, 'Health aspects associated with wind turbine noise: results from three field studies', *Noise Control Engineering Journal*, vol. 59, no. 1, pp. 47–53.

[a] See individual studies for additional details not provided here:

1. Pedersen, E & Waye, KP 2004, 'Perception and annoyance due to wind turbine noise: a dose–response relationship', *Journal of the Acoustical Society of America*, vol. 116, no. 6, pp. 3460–3470.
2. Pedersen, E & Persson Waye, K 2007, 'Wind turbine noise, annoyance and self-reported health and well-being in different living environments', *Occupational and Environmental Medicine*, vol. 64, no. 7, pp. 480–486.
3. Pedersen, E, van den Berg, F, Bakker, R & Bouma, J 2009, 'Response to noise from modern wind farms in The Netherlands', *Journal of the Acoustical Society of America*, vol. 126, no. 2, pp. 634–643.

**Affiliation/source of funds [2]** [a]

| **Study design [3]** | **Level of evidence [4]** | **Location/setting [5]** Sweden; The Netherlands. |
|---|---|---|
| Cross-sectional study. | IV | **Proximity/distance:**[a] |

**Exposure description [6]**

**Wind farm details:** [a]

**Specific exposure details:** [a]

**Sample size [7]**

Total respondents with complete data across three studies, n=1661 (total number who received survey not reported [a]).

**Control(s) description [8]**

No non-exposed groups were included in the study. Responder characteristics across different types of environmental and/or noise exposure were reported; however, no analysis based on these subgroups was presented in Pedersen 2011 or the individual studies used for the analysis.

**Sample size [9]**

See 'Population characteristics'.

**Population characteristics [10]**

**Exposure group:**
Not reported. [a]

| | |
|---|---|
| **Length of follow-up [11]**<br><br>NA (cross-sectional study) | **Outcome(s) measured and/or analyses undertaken [12]**<br><br>(a) association between A-weighted sound pressure levels and self-reported health symptoms/responses including annoyance outdoors and indoors, sleep interruption, chronic disease (unspecified), diabetes, hypertension, cardiovascular disease, tinnitus, impaired hearing, headache, undue tiredness, tension and stress, and irritability;<br>(b) association between annoyance outdoors due to wind turbine noise and the self-reported health symptoms listed at (a);<br>(c) association between annoyance indoors due to wind turbine noise and self-reported health symptoms listed at (a). |
| **INTERNAL VALIDITY**<br><br>**Confounding subscale [13]**<br><br>***Comment on sources of confounding:***<br>Poor reporting of participant characteristics. No baseline health data were provided. Adjustment for age, sex and economic benefit was performed in NL-07. Adjustment for age and sex in SWE-00 and SWE-05 results. Other plausible confounders not addressed ie chronic disease and risk factors for chronic disease, occupation, education, employment, terrain, urbanisation, background noise, and turbine visibility.<br><br>**Bias subscale [14]**<br><br>***Comment on sources of bias:***<br>Sample selection bias is more likely with response rates below 70%, as was the case for all three of the studies. Self-report of outcomes so possibility of outcome misclassification. Uncertain success of masking of study intent, so there is potential for recall bias. | **EXTERNAL VALIDITY**<br><br>**Generalisability [15]**<br><br>Potential for differences between the total population living near the included wind farms and those that responded to questionnaire.<br><br>**Applicability [16]**<br><br>Unknown whether the population characteristics and the wind turbine exposures of those living near wind farms in Sweden and The Netherlands are comparable to those living near wind farms in Australia. |
| **Reporting subscale [17]**<br><br>***Comment on quality of reporting:***<br>Fair, as most aspects were addressed adequately, with the exception of baseline demographic characteristics. | |

**Chance [18]**

There was the possibility of spurious significant associations because of the multiple statistical analyses undertaken.

**Overall quality assessment (descriptive) [19]**

On the basis of the Internal Validity assessment made on each of the individual studies, and the detailed critical appraisal of the studies given in Table 7, this re-analysis is considered poor quality for the purpose of this review.

An individual quality assessment of the studies is given above.

Good attempt to determine consistency of results between studies.

## RESULTS

**Adverse effect outcomes [20]**

*Association between A-weighted sound pressure levels (independent, continuous variable) and variables measuring response and/or effect (dependent, binary variable) tested with logistic regression.*

| | Study group | | |
|---|---|---|---|
| | SWE-00[a] n=319–333[c] | SWE-05[a] n=720–744[c] | NL-07[b] n=639–678[c] |
| Self-reported symptoms | | | |
| Annoyance outdoors | **1.24 [1.13,1.36]**[d] | **1.14 [1.03,1.27]** | **1.18 [1.12,1.24]** |
| Annoyance indoors | **1.38 [1.20,1.57]** | **1.42 [1.17,1.71]** | **1.20 [1.13,1.27]** |
| Sleep interruption | **1.12 [1.03,1.22]** | 0.97 [0.90,1.05] | 1.03 [1.00,1.07] |
| Chronic disease | 0.97 [0.89,1.05] | 1.01 [0.96,1.07] | 0.98 [0.95,1.01] |
| Diabetes | 0.96 [0.79,1.16] | 1.13 [1.00,1.27] | 1.00 [0.92,1.03] |
| High blood pressure | 1.03 [0.90,1.17] | 1.05 [0.97,1.13] | 1.01 [0.96,1.06] |
| Cardiovascular disease | 0.87 [0.68,1.10] | 1.00 [0.88,1.13] | 0.98 [0.91,1.05] |
| Tinnitus | **1.25 [1.03,1.50]** | 0.97 [0.88,1.07] | 0.94 [0.85,1.04] |
| Impaired hearing | 1.09 [0.93,1.27] | 1.05 [0.95,1.15] | 1.01 [0.94,1.10] |
| Headache | 0.95 [0.88,1.02] | 1.04 [0.99,1.10] | 1.01 [0.98,1.04] |
| Undue tiredness | 0.95 [0.88,1.02] | 0.98 [0.93,1.03] | 1.02 [0.99,1.05] |
| Tense and stressed | 1.02 [0.94,1.10] | 1.00 [0.95,1.05] | 1.01 [0.98,1.04] |
| Irritable | 1.03 [0.96,1.11] | 1.00 [0.96,1.06] | 1.01 [0.98,1.04] |

**Bold text indicates statistically significant association.**
[a] Adjusted for age and sex.
[b] Adjusted for age, sex and economic benefits.
[c] Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases, that is, the respondents not answering single questions in the questionnaire.
[d] [95% CI]

*Association between annoyance outdoors due to wind turbine noise (independent, continuous variable) and variables measuring response and/or effect (dependent, binary variable) tested with logistic regression.*

| | Study group | | |
|---|---|---|---|
| | SWE-00[a] n=319–333[c] | SWE-05[a] n=720–744[c] | NL-07[b] n=658–672[c] |
| Self-reported symptoms | | | |
| Sleep interruption | **2.26 [1.76,2.90]**[d] | **1.71 [1.35,2.17]** | **1.78 [1.49,2.14]** |
| Chronic disease | 0.90 [0.71,1.08] | 0.90 [0.74,1.26] | 0.98 [0.81,1.19] |
| Diabetes | 0.69 [0.37,1.31] | 0.71 [0.40,1.28] | **1.70 [1.14,2.56]** |

| | | | |
|---|---|---|---|
| High blood pressure | 0.82 [0.55,1.22] | 1.10 [0.84,1.45] | 0.86 [0.64,1.17] |
| Cardiovascular disease | 1.07 [0.58,1.98] | 1.00 [0.64,1.55] | 0.95 [0.65,1.38] |
| Tinnitus | 1.55 [0.95,2.53] | **0.88 [0.60,0.98]** | 0.82 [0.45,1.48] |
| Impaired hearing | 1.03 [0.96,1.19] | 0.78 [0.51,1.21] | 1.13 [0.76,1.67] |
| Headache | **1.24 [1.01,1.51]** | 1.04 [0.86,1.26] | **1.25 [1.04,1.50]** |
| Undue tiredness | 1.22 [1.00,1.49] | 1.12 [0.93,1.35] | 1.10 [0.93,1.31] |
| Tense and stressed | 1.25 [1.00,1.56] | 1.22 [1.00,1.50] | **1.27 [1.07,1.50]** |
| Irritable | **1.36 [1.10,1.69]** | 1.22 [1.00,1.49] | **1.27 [1.07,1.50]** |

**Bold text indicates statistically significant association.**
[a] Adjusted for age, sex, and A-weighted sound pressure levels.
[b] Adjusted for age, sex, A-weighted sound pressure levels, and economic benefits.
[c] Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases, that is, the respondents not answering single questions in the questionnaire.
[d] [95% CI]

*Association between annoyance indoors due to wind turbine noise (independent, continuous variable) and variables measuring response and/or effect (dependent, binary variable) tested with logistic regression.*

| | | Study group | |
|---|---|---|---|
| | SWE-00[a] n=318–331[c] | SWE-05[a] n=719–743[c] | NL-07[b] n=624–659[c] |
| Self-reported symptoms | | | |
| Sleep interruption | **2.62 [1.90, 3.61]**[d] | **2.58 [1.79, 3.71]** | **2.03 [1.66, 2.47]** |
| Chronic disease | 0.93 [0.69, 1.25] | 0.94 [0.68, 1.31] | 1.05 [0.09, 1.28] |
| Diabetes | 0.73 [0.30, 1.75] | 0.59 [0.22, 1.59] | **1.62 [1.10, 2.40]** |
| High blood pressure | 0.07 [0.36, 1.19][e] | 0.85 [0.52, 1.38] | 0.83 [0.59, 1.16] |
| Cardiovascular disease | 0.99 [0.46, 2.17] | 0.97 [0.49, 1.94] | 0.76 [0.47, 1.22] |
| Tinnitus | 1.25 [0.77, 2.05] | 0.57 [0.24, 1.33] | 0.67 [0.28, 1.57] |
| Impaired hearing | 1.14 [0.72, 1.79] | 0.56 [0.24, 1.32] | 1.20 [0.80, 1.80] |
| Headache | 1.07 [0.83, 1.37] | 1.11 [0.81, 1.52] | **1.28 [1.06, 1.54]** |
| Undue tiredness | **1.36 [1.05, 1.77]** | 1.00 [0.95, 1.80] | 1.15 [0.96, 1.37] |
| Tense and stressed | 1.03 [0.79, 1.35] | 1.07 [0.77, 1.48] | **1.24 [1.04, 1.48]** |
| Irritable | 1.22 [0.93, 1.61] | 1.23 [0.80, 1.72] | **1.26 [1.06, 1.50]** |

**Bold text indicates statistically significant association.**
[a] Adjusted for age, sex, and A-weighted sound pressure levels.
[b] Adjusted for age, sex, A-weighted sound pressure levels, and economic benefits.
[c] Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases, that is, the respondents not answering single questions in the questionnaire.
[d] [95% CI].
[e] OR and 95%CI as printed in Pedersen 2011.

| **Exposure group [21]** | **Control group [22]** | **Measure of effect / effect size [23]** | **Harms (NNH) [24]** |
|---|---|---|---|
| See 'Adverse effect outcomes' [20]. | NA | **95% CI [25]**<br>See [20]. | **95% CI [25]**<br>See [20]. |

| **Public health importance (1–4) [26]** | **Relevance (1–5) [27]** |
|---|---|
| The majority of the statistically significant results identified were health-related effects but not health effects *per se*. Tinnitus, diabetes and headache are health outcomes and could possibly be ranked 2 according to NHMRC criteria (tinnitus reduced in one study, while diabetes and headache increased each in one study). However, these results were not replicated in other studies. | 1 |
| **Comments [28]** | |
| Cross-sectional design cannot provide evidence of cause and effect. The majority of the self-reported health outcomes are patient-relevant. Annoyance is a subjective outcome of uncertain significance to health. Good attempt at controlling for confounding in individual studies, although several possible confounders were not measured or adjusted for. The authors comment appropriately on the possibility of statistical associations arising by chance (i.e. through multiple statistical testing) and so were cautious in attributing an association unless it independently occurred in all three studies. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects. | |

Abbreviations: NR = not reported; NC = not calculable

**Explanatory notes**

[1] Full reference citation details

[2] Details of how the study was funded or other relevant affiliations of the authors (designed to expose potential conflicts of interest)

[3] The study type (e.g. RCT, case-control study, cohort study), with additional detail where relevant

[4] As per the NHMRC levels of evidence in Merlin, Weston and Tooher (2009) or NHMRC (2009)

[5] Country/setting (e.g. detail on location in rural area, wind farm distance/proximity to study participants and turbine visibility)

[6] Detail on the exposure, including the type of wind farm, number of turbines, design/model of turbines, age of turbines, when construction of the wind farm was completed, community participation in decision making etc. Detail is required on the specific exposures—audible noise, infrasound/inaudible noise, shadow flicker, electromagnetic radiation, e.g. dose/level of exposure

[7] Number of participants enrolled in the exposure group

[8] The type of control used. There may be more than one comparator (e.g. no wind farm (no exposure), different type of wind farm)

[9] Number of participants enrolled in the comparison/control group(s)

[10] Any factors that may confound/influence the results and/or the external validity (see below) of the results (e.g. age, sex, comorbidities, existing medications, socioeconomic status, baseline attitudes to wind farm siting, education level, occupation (e.g. shift work), psychosocial stressors, financial implications of wind farm siting)

[11] Length of follow-up of the participants

[12] The outcomes studied (all adverse health effects mentioned in the study)

**INTERNAL VALIDITY (QUALITY ASSESSMENT)**

[13] Report outcomes of use of modified Downs & Black checklist for the Confounding subscale. Comment on likelihood of confounding having affected the results and justify

[14] Report outcomes of use of modified Downs & Black checklist for the Bias subscale. Comment on likelihood of bias having affected the results and justify

**EXTERNAL VALIDITY**

[15] Report outcomes of use of modified Downs & Black checklist for the External Validity subscale. Comment on generalisability of the study results and justify; that is, are the participants in the study so different from the target population for the NHMRC recommendation that the results may not be generalisable to them?

[16] Is the exposure in the study so different from the exposures likely to occur in Australia that the results may not be applicable?

[17] Report outcomes of use of modified Downs & Black checklist for the Reporting subscale. Comment on appropriateness of reporting in the study

[18] When assessing the role of chance, note the use of multiple statistical testing and data dredging, which may result in spurious statistically significant results

[19] Describe your assessment (in words) of the overall quality of the study. Is the study quality good enough that you have confidence in the results?

**RESULTS**

**Allowing one row for each relevant outcome, enter the following data from the results of the study:**

[20] The outcome relevant for this entry in the database (Note: more than one table may be required if there are several outcomes relevant to different questions)

[21] For binary outcomes, show numbers of participants with the outcome. For continuous outcomes, show means ± standard deviations; or medians and interquartile ranges

[22] For binary outcomes, show numbers of participants with the outcome. For continuous outcomes, show means ± standard deviations; or medians and interquartile ranges. Add number of columns as needed (e.g. 3-arm trials)

[23] Absolute and relative measures of effect and measure of variability, for example risk differences (absolute risk reduction or absolute risk increase), mean differences, relative risk, odds ratio

[24] A measure of harm, when the exposure increases the risk of specified adverse outcomes. The number needed to expose to harm (NNH) = the number of participants who, if they receive the exposure, would lead to one additional person being harmed compared with participants who are not exposed; calculated as 1/absolute risk increase, rounded up to the next highest whole number

[25] 95% confidence interval (CI) for all measures, if available; otherwise, use p value (be explicit on what comparison the p value relates to)

[26] Insert the appropriate rating from the scale provided at p. 23 of the NHMRC toolkit publication: *How to use the evidence: assessment and application of scientific evidence*

[27] Insert the appropriate rating from the scale provided at p. 28 of the NHMRC toolkit publication: *How to use the evidence: assessment and application of scientific evidence*

[28] Add your overall comments regarding the interpretation or implications of this study.

# APPENDIX C – EXCLUDED ARTICLES

## Study design unsuitable

Pedersen, E, Hallberg, LRM & Waye, KP 2007, 'Living in the vicinity of wind turbines: a grounded theory study', *Qualitative Research in Psychology* vol. 4, no. 1–2, pp. 63.

Alves-Pereira, M and Castelo Branco, NAA 2007, ‘In-home wind turbine noise is conducive to vibroacoustic disease’, *Proceedings of the Second International Meeting on Wind Turbine Noise*, Lyon, France, pp. 20–21. <www.confweb.org/wtn2007/ABSTRACTS_WTN2007.pdf>.

## Study outcome(s) unsuitable

Bilski, B 2012, 'Factors influencing social perception of investments in the wind power industry with an analysis of influence of the most significant environmental factor—exposure to noise', *Polish Journal of Environmental Studies*, vol. 21, no. 2, pp. 289–295.

Bond, S 2008, 'Attitudes towards the development of wind farms in Australia', *Environmental Health*, vol. 8, no. 3, pp. 19–32.

Friman, M 2011, *Directivity of sound from wind turbines: a study on the horizontal sound radiation pattern from a wind turbine*, Department of Aeronautical and Vehicle Engineering, The Marcus Wallenberg Laboratory for Sound and Vibration Research, Stockholm.

Kaldellis, JK, Garakis, K & Kapsali, M 2012, 'Noise impact assessment on the basis of onsite acoustic noise immission measurements for a representative wind farm', *Renewable Energy*, vol. 41, no. 1, pp. 306–314.

Kirchner, JC 2012, ‘Acoustic emission characterization of six wind turbines: a diagnostic tool to isolate, identify, and quantify point score contributors to a wind turbine’s noise’, Appalachian State University.

Lack, CA 2010, *Urban wind turbines,* Tallinn University of Technology, Faculty of Mechanical Engineering, Barcelona.

Mitchell, AJ 2004, *Wind turbine noise*, University of Canterbury, Department of Mechanical Engineering, Christchurch.

Palmer, W 2011, 'Collecting data on wind turbine sound to identify causes of identified concerns', *Proceedings of Meetings on Acoustics*, vol. 12. pp. 040003.

Velliyur Ramachandran, KG 2010, *An aeroacoustic analysis of wind turbines*, <http://rave.ohiolink.edu/etdc/view?acc%5Fnum=osu1293650904>.

Watts, CA, Schluter, PJ & Whiting, R 2005, 'Public opinion of a proposed wind farm situated close to a populated area in New Zealand: results from a cross-sectional study', *Environmental Health*, vol. 5, no. 3, pp. 73–83.

## Duplicated study or data

Janssen, S, Vos, H, Eisses, AR & Pedersen, E 2010, 'Predicting annoyance by wind turbine noise', Proceedings of InterNoise, 39th International congress of noise control engineering, Lisbon, 13–16 June 2010.

Janssen, SA, Eisses, AR, Pedersen, E & Vos, H 2009, 'Exposure-response relationships for annoyance by wind turbine noise: a comparison with other stationary sources', Proceedings of Euronoise, 8th European conference on noise control, Edinburgh, 26–28 October 2009.

Michaud, DS & Keith, SE 2007, 'Evaluating the potential health impacts of wind turbine noise for environmental assessments', *Wind Turbine Noise*, vol. 24.

Pedersen, E 2007, Human response to wind turbine noise? Perception, annoyance and moderating factors, Goteborg University, Sweden.

<http://gupea.ub.gu.se/dspace/bitstream/2077/4431/1/gupea_2077_4431_1.pdf>

Pedersen, E & Persson Waye, K 2003, 'Wind turbine noise; dose-response relationship', In: de Jong, RG, Houtgast, T, Franssen, EAM, Hofman, WF (eds), Proceedings of the 8th International Congress on Noise as a Public Health Problem, Rotterdam, 29 June – 3 July 2003, pp. 278–279.

Pedersen, E & Persson Waye, K 2008, 'Wind turbines: low-level noise sources interfering with restoration?' *Environmental Research Letters*, vol. 3, no. 1.

Pedersen, E, Van den Berg, F, Bakker, R & Bouma, J 2010, 'Can road traffic mask sound from wind turbines? Response to wind turbine sound at different levels of road traffic sound', *Energy Policy*, vol. 38, no. 5, pp. 2520–2527.

Persson Waye, K 2009, 'Perception and environmental impact of wind turbine noise', In: Proceedings of the InterNoise Congress 2009, 23–26 August, Ottawa, Canada.

## Study exposure unsuitable

Brown, CL, Hardy, AR, Barber, JR, Fristrup, KM, Crooks, KR & Angeloni, LM 2012, 'The effect of human activities and their associated noise on ungulate behavior', *PLoS ONE*, vol. 7, no. 7.

Carlos, RG 2008, ‘Very shallow water noise impact of offshore windfarms: parameters to be considered’, 15th International Congress on Sound and Vibration, Environmental Acoustics, Instituto de Acustica-CSIC, Madrid.

Harding, G, Harding, P & Wilkins, A 2008, 'Wind turbines, flicker, and photosensitive epilepsy: characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them', *Epilepsia*, vol. 49, no. 6, pp. 1095–1098.

Lee, S, Kim, K & Choi, W 2011, 'Annoyance caused by amplitude modulation of wind turbine noise', *Noise Control Engineering Journal*, vol. 59, no. 1, pp. 38–46.

Smedley, AR, Webb, AR & Wilkins, AJ 2010, 'Potential of wind turbines to elicit seizures under various meteorological conditions', *Epilepsia*, vol. 51, no. 7, pp. 1146–1151.

Verheijen, E, Jabben, J, Schreurs, E & Smith, KB 2011, 'Impact of wind turbine noise in The Netherlands', *Noise & Health*, vol. 13, no. 55, pp. 459463.

## Study not in English language

Chouard, CH 2006, 'Le retentissement du fonctionnement des eoliennes sur la sante de l'homme [Repercussions of wind turbine operations on human health]', French National Academy of Medicine. *Panorama du medecin*, vol. 20. *[note: English translation is available and this is not a study]*

Mroczek, B, Karakiewicz, B, Grochans, E, Zultak-Baczkowska, K & Rotter, I 2010, 'Health behaviour of adult inhabitants of towns located near wind farms in Poland', *Family Medicine and Primary Care Review,* vol. 12, no. 3, pp. 736–737.

## Study comparator unsuitable

Janssen, SA, Vos, H, Eisses, AR & Pedersen, E 2011, 'A comparison between exposure-response relationships for wind turbine annoyance and annoyance due to other noise sources', *Journal of the Acoustical Society of America*, vol. 130, no. 6, pp. 3746–3753.

Shepherd, KP, Grosveld, FW & Stephens, DG 1983, 'Evaluation of human exposure to the noise from large wind turbine generators', *Noise Control Engineering Journal*, vol. 21, no. 1, pp. 30–37.

## Article is not a study (wind energy discussion)

Asmus, P 2001, 'California crisis: the best argument yet for wind power', *Electricity Journal*, vol. 14, no. 3, pp. 42–47.

Barnett, J, Burningham, K, Walker, G & Cass, N 2012, 'Imagined publics and engagement around renewable energy technologies in the UK', *Public Understanding of Science*, vol. 21, no. 1, pp. 36–50.

Brisman, A 2005, 'The aesthetics of wind energy systems, *New York University Environmental Law Journal*, vol. 13, pp. 1–133.

Breukers, S 2006, 'Changing institutional landscapes for implementing wind power', Amsterdam University Press, <http://dare.uva.nl/document/133297>.

Cherry, JS 2008. 'The windy city: harnessing power in the neighborhood landscape', <http://dspace.mit.edu/handle/1721.1/44363>.

Cherry, TL & Whitehead, J 2004, 'The cheap-talk protocol and the estimation of the benefits of wind power', unpublished manuscript, Department of Economics, Appalachian State University.

DeCarolis, JF & Keith, DW 2001, 'The real cost of wind energy', *Science*, vol. 294, no. 5544, pp. 1000–1003.

Del Rosario, V & Goh, KH 2008, 'Community stakeholder management in wind energy development projects: a planning approach', unpublished Masters thesis, Faculty of Social Sciences, Umeå University, Sweden.

Dorobantu, NR 2011, 'Understanding "local" opposition to wind energy development in Australia: the intertwining link between procedural and distributional justice, health concerns and the people', unpublished Masters thesis, UCL School of Energy and Resources, Adelaide, South Australia.

EWEA 2005, ‘Wind energy - the facts, Volume 1: Technology’, European Wind Energy Association, <http://www.ewea.org/fileadmin/ewea_documents/documents/publications/WETF/WETF.pdf>

EWEA 2005, ‘Wind energy - the facts, Volume 4: Environment’, European Wind Energy Association, <http://www.ewea.org/fileadmin/ewea_documents/documents/publications/WETF/Facts_Volume_4.pdf>.

Ferrigno, KJ 2010, 'Challenges and strategies for increasing adoption of small wind turbines in urban areas', Thesis, Massachusetts Institute of Technology, viewed 4 October 2012, <http://dspace.mit.edu/handle/1721.1/59240>.

Firestone, J 2011, 'Perceptions and preferences regarding offshore wind power in the United States: the leading edge of a new energy source for the Americas', In: Devine-Wright, P. *Renewable energy and the public: from NIMBY to participation*, pp. 233–244.

Firestone, J & Kempton, W 2007, 'Public opinion about large offshore wind power: underlying factors', *Energy Policy*, vol. 35, no. 3, pp. 1584–1598.

Fritzsche, AF 1989, 'The health risks of energy production', *Risk Analysis,* vol. 9, no. 4, pp. 565–577.

Gross, C 2007, 'Community perspectives of wind energy in Australia: the application of a justice and community fairness framework to increase social acceptance', *Energy Policy*, vol. 35, no. 5, pp. 2727–2736.

Hasager, C, Badger, J, Bingöl, F, Clausen, N-E, Hahmann, A, Karagali, I, Badger, M & Alfredo Peña, A 2011, ‘Wind energy resources of the South Baltic Sea 2011’, World Renewable Energy Congress, 8–13 May 2011, Linköping, Sweden,<http://www.ep.liu.se/ecp/057/vol15/ecp057vol15.pdf>

Leary, J, Howell, R. & While, A 2011, 'Wind power for the poorest 2 billion'. <http://www.ewb-uk.org/system/files/Our%20Global%20Future%20-%20Research%20%2526%20Education%20Conference%202011_Proceedings.pdf>

Leistritz, FL & Coon, RC 2008, ‘Socioeconomic impacts of the Langdon Wind Energy Center’, Agribusiness & Applied Economics Report No. 627, North Dakota State University, Department of Agribusiness and Applied Economics.

Lukas, JA, Degreenia, TR, Peterson, KR & Sancetta, BC 2012, ‘21st century energy production and resulting impacts on society’, <https://www.wpi.edu/Pubs/E-project/Available/E-project-030112-003057/unrestricted/FinalIQPReport.pdf>.

Markandya, A & Wilkinson, P 2007, 'Electricity generation and health', *Lancet*, vol. 370, no. 9591, pp. 979–990.

Martin, GR & Smith, OA 2004, 'The world's largest wind energy facility in Nantucket Sound: deficiencies in the current regulatory process for offshore wind energy development, *Boston College Environmental Affairs Law Review*, vol. 31.

Orenstein, MR, tamburrini, A-L, Myles, E, Lee, M 2010, *Wind energy project in Alberta: issues in a farming community*, Habitat Health Impact Consulting, Calgary, Alberta.

Roosevelt, M 2002, 'The winds of change', *Time*, vol. 160, no. 9, pp. A40–44.

Sajan, AM & Amarnath, J 2010, 'Identification of environment and socio-economic impact factors for wind resource land mapping using ArcGIS, WaSP and Multi Criteria Decision analysis (MCDA)', In: *Recent advances in space technology services and climate change*, proceedings of a meeting held 13–15 November 2010, Chennai, India, pp. 457–459.

Shepherd, D & Billington, R 2011, 'Mitigating the acoustic impacts of modern technologies: acoustic, health, and psychosocial factors informing wind farm placement', *Bulletin of Science, Technology & Society*, vol. 31, no. 5, pp. 389–398.

Shrivastava, A 2010, 'An overview on wind energy in the global context', *International Journal of Engineering*, vol. 3, no. 3, pp. 369–374.

WHO 1986, *Health impact of different energy sources: a challenge for the end of the century*, report on a WHO meeting, Monte Carlo, 19–22 July 1983, Copenhagen.

Yue, CD, Liu, CM & Liou, EML 2001, 'A transition toward a sustainable energy future: feasibility assessment and development strategies of wind power in Taiwan', *Energy Policy*, vol. 29, no. 12, pp. 951–963.

## Article is not a study (commentary/opinion)

Bisbee, DW 2004, 'NEPA review of offshore wind farms: ensuring emission reduction benefits outweigh visual impacts', *Boston College Environmental Affairs Law Review*, vol. 31.

Chapman, S 2006, ‘A disease in search of a cause: a study of self--citation and press release pronouncement in the factoid of wind farms causing “vibroacoustic disease”.’ University of Sydney, Sydney.

Chapman, S 2011, 'Wind farms and health: who is fomenting community anxieties?', *Medical Journal of Australia*, vol. 195, no. 9, pp. 495–495.

Chapman, S 2012, 'Editorial ignored 17 reviews on wind turbines and health', *British Medical Journal* (Clinical research edn), vol. 344, p. e3366; author reply e3367.

Chapman S 2012, ‘Wind turbine syndrome: a classic “communicated” disease’, <http://theconversation.edu.au/wind-turbine-syndrome-a-classic-communicated-disease-8318>.

CHE Energy 2010, ‘Wind’, <http://envhist.wisc.edu/cool_stuff/energy/wind.shtml>.

Clarke, P 1995, 'Health & safety on wind farms - the PowerGen approach', In: Halliday, JS (ed.), Proceedings of the 17th British Wind Energy Association Conference, Warwick 19–21 July 1995, pp. 25–32.

Cummings, J 2012, 'Extrapolating beyond chinchillas: behavioral response ambiguity through the lens of variable human responses to moderate wind farm noise', *Advances in Experimental Medicine and Biology*, vol. 730, pp. 501–504.

Frey, BJ & Hadden, PJ 2007, ‘Noise radiation from wind turbines installed near homes: effects on health—with an annotated review of the research and related issues’, <http://www.viewsofscotland.org/library/turbines_and_health.php>

Hanning, CD 2012, 'Comments on wind turbine health impact study: report of independent expert panel’, Prepared for Massachusetts Departments of Environmental Protection and Public Health.

Hanning, CD & Evans, A 2012, 'Wind turbine noise', *British Medical Journal* (Clinical research edn), vol. 344, p. e1527.

Harrison, JP 2011, 'Wind turbine noise', *Bulletin of Science, Technology & Society*, vol. 31, no. 4, pp. 256–261.

Horner, B, Jeffery, RD & Krogh, CME 2011, 'Literature reviews on wind turbines and health: are they enough?', *Bulletin of Science, Technology & Society*, vol. 31, no. 5, pp. 399–413.

Institute of Noise Control Engineering 2011, 'Proceedings of Noise Control Engineering Conference', INCE national conference, 25–27 July, Portland, Oregon, <http://www.proceedings.com/0123.html>.

McMurtry, RY 2011, 'Toward a case definition of adverse health effects in the environs of industrial wind turbines: facilitating a clinical diagnosis', *Bulletin of Science, Technology & Society*, vol. 31, no. 4, pp. 316–320.

National Institute on Deafness and Other Communication Disorders 2010, 'Scientist challenges the conventional wisdom that what you can't hear won't hurt you', <http://www.nidcd.nih.gov/news/releases/10/pages/07_28_10.aspx>

Pedersen E, Persson Waye K, 2005, 'Human response to wind turbine noise: annoyance and moderating factors', presented at the First International Meeting on Wind Turbine Noise, Berlin, 17–18 October 2005 Berlin, Germany, <http://www.wolfgang-neumann-gmm.de/upload/Pedersen.pdf>.

Phillips, C 2011, 'Properly interpreting the epidemiologic evidence about the health effects of industrial wind turbines on nearby residents', *Bulletin of Science, Technology & Society*, vol. 31, no. 4, pp. 303–315.

Pierpont, N 2006, 'Health effects of wind turbine noise', *Journal of Sound Vibration*,

Shepherd, D 2012, 'Wind farms and health: who is fomenting community anxieties?', *Medical Journal of Australia*, vol. 196, no. 2, pp. 108–108.

Sullivan S 2009, 'They're saying what about wind Farms? The case for early and engaged public outreach', energybiz, < http://www.energybiz.com/article/09/01/theyre-saying-what-about-wind-farms-case-early-and-engaged-public-outreach>.

Unknown author 2011, 'Understanding wind energy: questions posed to the experts (sound/noise level)', <http://www.macalester.edu/understandingwind/CategorizedQuestions.pdf>.

## Article is not a study (narrative review)

Alberts, DJ 2006, 'Addressing wind turbine noise', 2006, Lawrence Technology University, <http://www.maine.gov/doc/mfs/windpower/pubs/pdf/AddressingWindTurbineNoise.pdf>

Bellhouse, G 2004, *Low-frequency noise and infrasound from wind turbine generators: a literature review*, Prepared for EECA, BelAcoustic Consulting, NZ, 2004.

Bolin, K, Bluhm, G, Eriksson, G & Nilsson, ME 2011, 'Infrasound and low-frequency noise from wind turbines: exposure and health effects', *Environmental Research Letters*, vol. 6, no. 3.

Bronzaft, AL 2011, 'The noise from wind turbines: potential adverse impacts on children's well-being', *Bulletin of Science, Technology & Society*, vol. 31, no. 4, pp. 291–295.

Colby, WD, Dobie, R, Leventhall, G, Lipscomb, DM, McCunney, RJ, Seilo, MT & Søndergaard, B 2009, *Wind turbine sound and health effects: an expert panel review*, American Wind Energy Association.

Copes, R & Rideout, K 2009, 'Wind turbines and health: a review of evidence', presentation by the National Collaborating Centre for Environmental Health, Ontario's Public Health Agency, 2009.

Gulden, WE 2011, 'A review of the current evidence regarding industrial wind turbines and property values from a homeowner's perspective', *Bulletin of Science, Technology & Society*, vol. 31, no. 5, pp. 363–368.

Hanning, C 2010, 'Wind turbine noise, sleep and health', The Society for Wind Vigilance, <http://www.windvigilance.com/about-adverse-health-effects/wind-turbine-noise-sleep-and-health-by-dr-hanning>.

Knopper, LD & Ollson, CA 2011, 'Health effects and wind turbines: a review of the literature', *Environmental health*, vol. 10, p. 78.

Leventhall, HG 2009, 'Wind turbine syndrome: an appraisal', Testimony before the Public Service Commission of Wisconsin, PSC Ref, vol. 121877.

McFadden, JD 2010, 'Wind turbines: a brief health overview', 2010, Presentation made to the Wisconsin Wind Siting Council, 17 May 2010, <http://www.wiwindinfo.net/impacts/JM%20Turbines%20-%20Health%20PPT%205-17-10.pdf>

Moorhouse, A, von Hünerbein, S, Piper, B, Adams M 2007, 'Research into aerodynamic modulation of wind turbine noise: final report', University of Salford, Manchester, UK, <http://www.acoustics.salford.ac.uk/res/moorhouse/?content=am>

Nordman, E 2010, 'Wind power and human health: flicker, noise, and air quality', Biology Department, Grand Valley State University, <http://scholarworks.gvsu.edu/cgi/viewcontent.cgi?article=1008&context=bioreports&sei-redir=1&referer=http%3A%2F%2Fwww.google.com.au%2Furl%3Fs>

Pierpont, N 2006, 'Wind turbine syndrome', Testimony before the New York Legislature Energy Committee, 2006.

Rideout, K, Copes, R & Bos, C 2010, *Wind turbines and health*, National Collaborating Centre for Environmental Health, Vancouver.

Salt, AN & Hullar, TE 2010, 'Responses of the ear to low-frequency sounds, infrasound and wind turbines', *Hearing Research*, vol. 268, no. 1–2, pp. 12–21.

Shepherd, D 2010, 'Wind turbine noise and health in the New Zealand context', In: Rapley, BI and Bakker, HHC (eds), *Sound, noise, flicker and the human perception of wind farm activity*. Atkinson Rapley Consulting, Palmerston North, New Zealand.

Sovacool, BK 2009, 'Exploring and contextualizing public opposition to renewable electricity in the United States', *Sustainability*, vol. 1, no. 3, pp. 702–721.

Thorne, B 2011, 'The problems with “noise numbers” for wind farm noise assessment', *Bulletin of Science, Technology & Society*, vol. 31, no. 4, pp. 262–290.

## Article is not a study (guidelines, regulations)

NSW Parliament 2012, ’Wind farms’, e-brief 13/2012, <http://www.parliament.nsw.gov.au/prod/parlment/publications.nsf/key/WindFarms:regulatorydevelopmentsinNSW/$File/Wind+Farms+regulatory+developments+in+NSW.pdf>.

AECOM 2011, ‘Wind farm noise statutory nuisance complaint methodology’, <http://www.defra.gov.uk/publications/files/pb-13584-windfarm-noise-statutory-nuisance.pdf>.

Coy, J, Sadaka, N & Lamborn, J 2004, ‘Siting criteria for wind farms in Australia’, New Zealand Society for Sustainability Engineering and Science.

Kamperman, GW & James, RR 2008, 'Simple guidelines for siting wind turbines to prevent health risks', presented at Institute of Noise Control Engineering (INCE), 28–31 July 2008, Kamperman Associates Inc.

Kamperman, GW & James, RR 2008, 'The “how to” guide to siting wind turbines to prevent health risks from sound', Windaction.org, < http://www.savethebluffs.ca/archives/files/kamperman-james-8-26-08-report.pdf>.

Kamperman, GW & James, RR, 2009, 'Guidelines for selecting wind turbine sites', *Sound and Vibration*, vol. 43, no. 7, pp. 8–12.

Keith, SE, Michaud, DS & Bly, SHR 2008, 'A proposal for evaluating the potential health effects of wind turbine noise for projects under the Canadian Environmental Assessment Act', *Journal of Low Frequency Noise Vibration and Active Control*, vol. 27, no. 4, pp. 253–265.

Ledec, GC, Rapp, KW, Aiello, RG, 2011, *Greening the wind: environmental and social considerations for wind power development,* a World Bank study, The World Bank, Washington, DC.

National Research Council 2007, ‘Environmental impacts of wind-energy projects’, The National Academies Press, Washington, DC.

Renewable UK 2012, ‘Guidelines for onshore and offshore wind farms’, <http://www.bwea.com/pdf/HSGuidelines.pdf>.

Government of Nova Scotia 2012, ‘Wedgeport Wind Farm Project’, <http://www.gov.ns.ca/nse/ea/wedgeport.wind.farm.project/Sections_1-5.pdf>.

Surugiu, L & Paraschivoiu, I 2000, 'Environmental, social and economic aspects of wind energy', Proceedings of Energy Conversion Engineering Conference and Exhibit (IECEC), 35th Intersociety, vol. 2, pp. 1167–1174.

van der Horst, D, Toke, D & Forest, T 2010, 'Exploring the landscape of wind farm developments; local area characteristics and planning process outcomes in rural England', *Land Use Policy*, vol. 27, no. 2, pp. 214–221.

Western Area Power Administration 2011, ‘South Dakota Prairie Winds Project DOE/EIS #0418’, <http://www.ymp.gov/sites/prod/files/nepapub/nepa_documents/RedDont/EIS-0418-DEIS-2010.pdf>.

## Article is not a study (wind turbine background)

Bastasch, M, van Dam, J, Sondergaard, B & Rogers, A 2006, 'Wind turbine noise: an overview', *Canadian Acoustics*, vol. 34, no. 2.

Bray, W & James, R 2011, 'Dynamic measurements of wind turbine acoustic signals, employing sound quality engineering methods considering the time and frequency sensitivities of human perception', <http://www.windaction.org/documents/33315>.

Chen, HA & Narins, P 2012, 'Wind turbines and ghost stories: the effects of infrasound on the human auditory system', *Acoustics Today*, vol. 8, no. 2, pp. 51–56.

Grimm, B 2009, 'Quantifying the visual effects of wind farms: a theoretical process in an evolving Australian visual landscape', PhD thesis, University of Adelaide, South Australia.

Møller, H, Pedersen, S, Staunstrup, JK & Pedersen, CS, 2012, *Assessment of low-frequency noise from wind turbines in Maastricht*, Section of Acoustics, Department of Development and Planning, Aalborg University, Denmark.

Lodders, J 2010, 'Monitoring the sound and vibration of wind turbines', Proceedings of the 6th Australasian Congress on Applied Mechanics, Perth, WA, Engineers Australia, pp. 1207–1216, <http://search.informit.com.au/documentSummary;dn=019280420676123;res=IELENG> ISBN: 9780858259416>.

Møller, H & Pedersen CS 2010, *Low-frequency noise from large wind turbines*, Section of Acoustics, Aalborg University, Denmark.

New England Wind Forum 2011, 'Understanding the current science, regulation, and mitigation of shadow flicker: a NEWEEP Webinar, <http://www.windpoweringamerica.gov/newengland/filter_detail.asp?itemid=2967>.

Pedersen, S & Møller, H 2006, 'Low-frequency noise from large wind turbines: quantification of the noise and assessment of the annoyance', Aalborg University, <http://vbn.aau.dk/en/projects/lavfrekvent-stoej-fra-store-vindmoeller--kvantificering-af-stoejen-og-vurdering-af-genevirkningen(df53eb17-01c9-42bb-9677-7dd805d4e8fc).html>.

Punch, J, James, R & Pabst, D 2010, 'Wind turbine noise: what audiologists should know', *Audiology Today*, vol. 22, no. 4, pp. 20–31.

Ramakrishnan, R 2009, 'Wind farms and noise', Proceedings of Inter-Noise 2009, August 2009, Ottawa, Ontario.

Salt, A & Kaltenbach, J 2011, 'Infrasound from wind turbines could affect humans', *Bulletin of Science, Technology & Society*, vol. 31, no. 4, pp. 296–302.

Thorne, R 2009, 'Assessing intrusive noise and low amplitude sound', PhD thesis, Institute of Food, Nutrition and Human Health, Massey University, New Zealand.

Van den Berg, GP 2005, 'The beat is getting stronger: the effect of atmospheric stability on low-frequency modulated sound of wind turbines', *Journal of Low Frequency Noise Vibration and Active Control*, vol. 24, no. 1, pp. 1–23.

Warren, C, Niezrecki, C & Avitabile, P 2011, 'Determination of wind turbine operating deflection shapes using full-field 3D point-tracking', Proceedings of the 29th International Modal Analysis Conference, Jacksonville, Florida.

# APPENDIX D – SUMMARY OF LITERATURE PROVIDED BY THE NHMRC

Table 40 lists all articles supplied for this review by the NHMRC in categories of ‘existing literature’ and ‘submitted literature’. Literature in the ‘submitted literature’ category comprised all material that was provided to the NHMRC for consideration in the review during the public call for literature conducted in September 2012. Literature in the ‘existing literature’ category comprised material from NHMRC files on wind farms and human health, and material that had been previously submitted to the NHMRC by stakeholders.

The table identifies each document and the action taken (include or exclude) in regard to that document. Each document was retrieved and assessed by the researchers for eligibility of inclusion in the systematic reviews’ evidence-base. Documents that were included have been identified; and where a document has been excluded, the primary reason behind that action is indicated.

## Table 40 Summary of literature received from the NHMRC

| Author | Year | Title | Article type/source | Action |
|---|---|---|---|---|
| **Existing literature** | | | | |
| BelAcoustic Consulting | 2004 | *Low-frequency noise and infrasound from wind turbine generators: a literature review* | Report | Narrative review, background information on turbines, no health outcomes; exclude |
| Board on Environmental Studies and Toxicology | 2007 | *Environmental Impacts of wind-energy projects* | Book | Background information on wind farms, human health outcomes not considered; exclude |
| CanWEA | 2009 | *Addressing concerns with wind turbines and human health* | Position statement | Opinion piece with list of references; exclude |
| Chatham-Kent Public Health Unit | 2008 | *The health impact of wind turbines: a review of the current white, grey and published literature* | Report | Narrative review; exclude |
| Chief Medical Officer of Health (Canada) | 2010 | *The potential health impact of wind turbines* | Report | Narrative review; exclude |
| Colby WD, Dobie R, Leventhall G, Lipscomb DM, McCunney RJ, Seilo MT, Sondergaard B | 2009 | *Wind turbine sound and health effects: an expert panel review* | Report | Narrative review conducted by expert panel, no new/additional data presented; exclude |
| Fiumicelli D | 2011 | *Wind farm noise-dose response* | Report | Background information on wind turbine noise impacts and dose effects; exclude |
| Jakobsen J | 2005 | *Infrasound emission from wind turbines* | Report | Background information on wind turbine infrasound measurement; exclude |
| Knopper LD, Ollson CA | 2011 | *Health effects and wind turbines: a review of the literature* | Report | Systematic search of peer-reviewed literature using key words in the Web of Knowledge, key word search using Google for popular literature, narrative review of findings, no new data reported; exclude |
| Leventhall G | 2004 | *Low-frequency noise and annoyance <http://www.noiseandhealth.org/text.asp?2004/6/23/59/31663>* | Report | Background information on wind turbine noise measurement; exclude |
| Massachusetts Dept of Public Health and Dept of | 2012 | *Wind turbine health impact study: report of independent expert panel* | Report | Background information on wind turbine features, narrative review of health impact |

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| Environmental Protection | | | | literature, no new data reported; exclude |
| Minnesota Dept of Health, Environmental Health Division | 2009 | *Public health impacts of wind turbines* | Report | Background information of wind turbine features, narrative review of health impact literature, no new data reported; exclude |
| Ohio Department of Health | 2008 | *Literature search on the potential health impacts associated with wind-to-energy turbine operations* | Report | Narrative review; exclude |
| Pedersen E, Halmstad H | 2003 | *Noise annoyance from wind turbines: a review* | Report | Narrative review; exclude |
| Roberts M, Roberts J (exponent) | 2009 | *Evaluation of the scientific literature on the health effects associated with wind turbines and low-frequency sound* | Report | Narrative review; exclude |
| Bolin K, Bluhm G, Eriksson G, Nilsson M | 2011 | Infrasound and low-frequency noise from wind turbines: exposure and health effects | Journal—*Environmental Research Letters* | Narrative review; exclude |
| Cappucio FP, Cooper D, D'Elia L, Strazzullo P, Miller M | 2011 | Sleep duration predicts cardiovascular outcomes: a systematic review and meta-analysis of prospective studies | Journal—*European Heart Journal* | Study—population unsuitable (cardiovascular disease); exclude |
| Chen HA, Narins P | 2012 | Wind turbines and ghost stories: the effects of infrasound on the human auditory system | Journal—*Acoustical Society of America* | Background information on wind turbine infrasound; exclude |
| Hanning C, Evans A | 2012 | Wind turbine noise | Journal—*British Medical Journal* | Opinion paper; exclude |
| Harding G, Harding P, Wilkins A | 2008 | Wind turbines, flicker and photosensitive epilepsy: characterising the flashing that may precipitate seizures and optimising guidelines to prevent them | Journal—*Epilepsia* | Background information on shadow flicker as possible cause of epilepsy; exclude |
| Jakobsen J | 2005 | Infrasound emission from wind turbines | Journal—*Low Frequency Noise, Vibration and Active Control* | Background information on wind turbine infrasound; exclude |
| Janssen SA, Voss H, Eisses E, Pedersen E | 2011 | A comparison between exposure–response relationships for wind turbine annoyance and annoyance due to other noise sources | Journal—*Acoustical Society of America* | Background information and modelling based on 3 previous studies, no new empirical data; exclude |
| Kamperman GW, James RR | 2009 | Guidelines for selecting wind turbines sites | Journal—*Sound and Vibration* | Guidelines for turbine site selection; exclude |
| McMurty R | 2011 | Toward a case definition of adverse health effects in the environs of industrial wind turbines: facilitating a clinical diagnosis | Journal—*Bulletin of Science, Technology & Society* | Background information on wind turbines health effects measurements; exclude |
| Moller H, Pedersen CS | 2011 | Low-frequency noise from large wind turbines | Journal—*Acoustical Society of America* | Background information on wind turbines; exclude |

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| Nishimura K | 1988 | The effects of infrasound on pituitary adreno-cortical response and gastric microcirculation in rats | Journal—*Low Frequency Noise and Vibration* | Study—population unsuitable (non-human); exclude |
| Pedersen E, Persson Waye K | 2008 | Wind turbines: low level noise sources interfering with restoration? | Journal—*Environmental Research Letters* | Duplicate study/data—duplication of included data (Pedersen and Larsman 2008); exclude |
| Pedersen E, van den Berg F, Bakker R, Bouma J | 2009 | Response to noise from modern wind farms in The Netherlands | Journal—*Acoustical Society of America* | Study—**include** (also identified in the black literature search) |
| Persson Waye K, Rylander R, Benton S, Leventhall G | 1997 | Effects on performance and work quality due to low-frequency ventilation noise | Journal—*Sound & Vibration* | Background information on low-frequency noise; exclude |
| Phillips CV | 2011 | Properly interpreting the epidemiologic evidence about the health effects of industrial wind turbines nearby residents | Journal—*Bulletin of Science, Technology & Society* | Background information on wind turbine health effects; exclude |
| Qibai CYH, Shi H | 2004 | An investigation on the physiological and psychological effects of infrasound on persons | Journal—*Low Frequency Noise, Vibration and Active Control* | Background information on infrasound effects on humans; exclude |
| Salt A, Kaltenbach J | 2011 | Infrasound from wind turbines could affect humans | Journal—*Bulletin of Science, Technology & Society* | Background information on wind turbine infrasound effects; exclude |
| Shepherd D, McBride D, Welch D, Dirks K, Hill E | 2011 | Evaluating the impact of wind turbine noise on health-related quality of life | Journal—*Noise & Health* | Study—**include** (also identified in the black literature search) |
| Sloven P | 2005 | LFN and the A-weighting | Journal—*Low Frequency Noise, Vibration and Active Control* | Background information on technical aspects to sound measurements; exclude |
| Smedley A, Webb A, Wilkins A | 2010 | Potential of wind turbines to elicit seizures under various meteorological conditions | Journal—*Epilepsia* | Background information of shadow flicker and epileptic seizures; exclude |
| Spyrak CH, Papadopoulou-Daifoti Z, Petounis A | 1978 | Norepinephrine levels in rat bran after infrasound exposure | Journal—*Psychology and Behaviour* | Study—population unsuitable (non-human); exclude |
| Ambrose SE, Rand RW | 2011 | *The Bruce McPherson infrasound and low-frequency noise study* | Report | Opinion paper—sound measurements and personal experience of symptoms at an individual home near a turbine; exclude |
| Bakker HHC, Rapley BI | 2011 | Problems measuring low-frequency sound levels near wind farms | Conference paper | Narrative review on human perceptions and measurement of low-frequency sound near wind farms; exclude |
| Bray W, James R | 2011 | Dynamic measurements of wind turbine acoustic signals, employing sound-quality engineering methods considering the time- and frequency-sensitivities of human perception | Conference paper | Background information on low-frequency sound and human perception; exclude |

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|---|---|---|---|---|
| Chapman S | 2011 | Wind farms and health: who is fomenting community anxieties? | Op-ed | Opinion paper; exclude |
| Chapman S | n.d. | Is there anything that wind turbines don't cause? Psychogenic aspects of 'wind turbine disease' | Presentation | Background information on psychogenic and attitudinal aspects to causes of health problems; exclude |
| Dickinson PJ | 2012 | A pragmatic view of wind turbine noise standard | Paper | Background information on NZ acoustic standards and characteristics of wind farm noise; exclude |
| E-coustic Solutions | n.d. | *Submission of comments related to proposed Ministry of the Environment Regulations to Implement the Green Energy and Green Economy Act, 2009* | Report | Background information on measurement of low-frequency and infrasound from wind farms, no health outcomes; exclude |
| enHealth | 2004 | *The health effects of environmental noise: other than hearing loss* | Report | Background on health effects of industrial noise; exclude |
| Environmental Review Tribunal | 2010 | Erikson V, Director, Ministry of the Environment | Legal evidence | Tribunal presentations—insufficient study details; exclude |
| Frey BJ, Hadden, PJ | 2012 | *Wind turbines and proximity to homes: the impact of wind turbine noise on health* | Report | Narrative review; exclude |
| Frey BJ, Hadden PJ | 2007 | *Noise radiation from wind turbines installed near homes: effects on health* | Report | Narrative review; exclude |
| Hall N, Ashworth P, Shaw H (CSIRO) | 2012 | *Exploring community acceptance of rural wind farms in Australia: a snapshot* | Report | Narrative review of community attitudes to wind farms with case studies; exclude |
| Hanning C | 2010 | Wind turbine noise and sleep: the torment of sleep disturbance | Presentation | Background information on the effects of noise on sleep; exclude |
| Hanning, C | 2010 | *Wind turbine noise, sleep and health* | Report | Narrative review; exclude |
| Hanning C, Nissenbaum M | 2011 | Selection of outcome measures in assessing sleep disturbance from wind turbine noise | Conference paper | Background information on sleep and noise disturbance; exclude |
| Harrison J | 2010 | No rules, no caution, no accountability | Presentation | Background information on regulation and modelling of wind turbine noise; exclude |
| Harry A | 2007 | *Wind turbines, noise and health* | Report—case series | Study—case series selected with symptoms they attributed to wind turbines, no comparative analysis; exclude |
| Health Protection Agency | 2010 | *Health effects of exposure to ultrasound and infrasound* | Report | Background information on environmental noise and health; exclude |

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| Health Protection Agency | 2010 | *Environmental noise and health in the UK* | Report | Background information on health and exposure to ultrasound and infrasound; exclude |
| Horner B | 2012 | NHMRC audit comments | Email communication | Commentary in response to the NHMRC report *Wind turbines and health: a rapid review of the evidence July 2010*; exclude |
| Hubbard HH, Shepherd KP | 1990 | *Wind turbine acoustics* | Report | Background information on wind turbine acoustics; exclude |
| Ison E | 2009 | *Rapid review of health impacts of wind energy* | Report | Narrative review on effects of energy production and wind farms; exclude |
| James R | 2010 | No rules, no caution, no accountability | Presentation | Background information on regulation and modelling of wind turbine noise; exclude |
| Krogh, C | 2011 | *Brief overview of references on noise including industrial wind turbines and adverse health effects* | Report | Background information on the effects of noise on humans; exclude |
| Krogh C, Horner B | 2011 | *A summary of new evidence: adverse health effects and industrial wind turbines* | Report | Opinion/discussion of evidence of health effects of wind turbines; exclude |
| Leventhall G | 2010 | Wind turbine syndrome: an appraisal | Presentation | Opinion/discussion of evidence for wind turbine syndrome; exclude |
| Leventhall G | 2003 | *A review of published research on low-frequency noise and its effects* | Report | Background information on low-frequency noise and its effects; exclude |
| Mills DA, Manwell JF | 2012 | *A brief review of wind power in Denmark, Germany, Sweden, Vermont and Maine: possible lessons for Massachusetts* | Report | Narrative review of wind power in Denmark, Sweden, Germany, Vermont and Maine; exclude |
| Moller H, Pedersen S, Stanstrup JK, Pedersen CS | 2012 | *Assessment of low-frequency noise from wind turbines in Maastricht* | Report | Background information on the measurement, impact and health effects of low-frequency noise; exclude |
| Moorhouse A, Hayes M, Von Hunderbein S, Piper B, Adams M | 2007 | *Research into aerodynamic modulation of wind turbine noise: final report* | Report | Background information on aerodynamic modulation of low-frequency wind turbine noise; exclude |
| National Research Council | 2007 | *Environmental impacts of wind-energy projects* | Book | Narrative review of assessment and measurement of the impact of wind turbines on the environment; exclude |
| National Toxicology Program | 2001 | *Brief review of toxicological literature* | Report | Background information on the impact of infrasound on the environment and |

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|---|---|---|---|---|
| | | | | humans; exclude |
| Nature and Society | 2011 | | Editorial—*Journal of the Nature and Society Forum* | Opinion/discussion papers on wind farms and ecology and controversies around wind farming; exclude |
| New South Wales Landscape Guardians | 2012 | *Peer-reviewed studies on health impacts of wind turbines* | Report | Narrative review; exclude |
| Nissenbaum M, Aramini J, Hanning C | 2011 | Adverse health effects of industrial wind turbines: a preliminary report | Conference paper | Duplicate study/data—an updated version identified and included (Nissenbaum, Aramini, Hanning 2012); exclude |
| Oregon Health Authority | 2012 | *Strategic health impact assessment on wind energy development in Oregon* | Report | Narrative review and assessment of health impact of wind energy development in Oregon; exclude |
| Pace Energy and Climate Centre | 2011 | *Case study: Maple Ridge and High Sheldon wind farms* | Report | Opinion/discussion of the impact of wind farming in New York State; exclude |
| Pedersen E | 2007 | Human response to wind turbine noise: perception, annoyance and moderating factors | Thesis | Duplicate study/data—duplication of included data (Pedersen & Persson Waye 2007); exclude |
| Phillips C | 2010 | *An analysis of the epidemiology and related evidence on the health effects of wind turbines on local residents* | Report | Opinion paper; exclude |
| Phipps R, Amati M, McCoard S, Fisher R | 2008 | Visual and noise effects reported by residents living close to Manawatu wind farms: preliminary survey results | Paper | Study—self-report survey of preliminary results with no relevant health outcomes; exclude |
| Pierpont N | 2009 | *Wind turbine syndrome: a report on a natural experiment* | Book | Background information—reporting on a collection of case reports but with no comparative analysis; exclude |
| Punch J, James R, Pabst D | 2010 | Wind turbine noise: what audiologists should know | Magazine | Narrative review; exclude |
| Rogers AL, Manwell JF, Wright S | 2006 | *Wind turbine acoustic noise* | Report | Background information on wind turbine acoustic noise; exclude |
| Salt A | 2010 | Infrasound: your ears 'hear' it but they don't tell your brain | Presentation | Background information on the impact of infrasound on humans; exclude |
| Shepherd D | 2012 | Response to 'Wind farms and health: who is fomenting community anxieties?' – Letters | Letter to editor | Commentary/opinion, correspondence with no data; exclude |

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| Sloth E | 2010 | Parameters influencing wind turbine noise | Presentation | Background information on factors affecting wind turbine noise; exclude |
| Sonus Pty Ltd | 2010 | *Infrasound measurements from wind farms and other sources* | Report | Background information on infrasound measurement; exclude |
| Stantec Consulting | 2011 | *Health effects and wind turbines: a review for renewable energy approval applications submitted under Ontario Regulation 359/09* | Report | Narrative review; exclude |
| Stewart J | 2006. | *Location, location, location: an investigation into wind farms and noise by the Noise Association* | Report | Background information on wind turbine noise and its impact; exclude |
| Swinbanks M | 2010 | Wind Energy Resource Zone Board comments: NASA–Langley wind turbine noise research | Email communication | Commentary/opinion, correspondence with no data; exclude |
| The Acoustics Group Pty Ltd | 2011 | *Peer review of acoustic assessment of Flyers Creek wind farm* | Report | Background information on acoustic assessment of a wind farm in NSW; exclude |
| Thorne B | 2011 | *Wind farm noise and human perception: a review* | Report | Background information of wind turbine effects and single case study, not systematic; exclude |
| Thorne R | 2012 | *Waubra & other Victorian wind farm noise impact assessments* | Report | Study—survey of residents living near wind farms; some health outcomes but study not yet completed; exclude |
| Thorne R | 2007 | Assessing intrusive noise and low-amplitude sound | Thesis | Background information on noise assessment; exclude |
| Thorne R, Shepherd D | 2011 | Wind turbine noise: why accurate prediction and measurement matter | Conference paper | Background information on noise measurement from wind turbines and noise annoyance; exclude |
| Boorowa District Landscape Guardians | Not dated | Wind energy in the Southern Tablelands | Flyer | Commentary/opinion; exclude |
| Unknown | 2010 | *Overview of references: adverse health effects of industrial wind turbines* | Report | Narrative review; exclude |
| Unknown | 2012 | *Summary of peer-reviewed references* | Report | Abstract list: with no eligible articles not previously included |
| Van den Berg GP | 2006 | *The sound of high winds: the effect of atmospheric stability on wind turbine sound and microphone noise* | Book/Report | Background information on wind turbine noise and measurement; exclude |
| Van den Berg GP | 2003 | Wind turbines at night: acoustical practice and sound research | Conference paper | Background information on wind turbine noise at night; exclude |

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| Von Hunerbein S, King A, Hargreaves J, Moorhouse A, Plack C | 2010 | *Perception of noise from large wind turbines* | Report | Background information on wind turbine noise perception and annoyance thresholds for measurement; exclude |
| World Health Organization | 2011 | *Burden of disease from environmental noise: quantification of healthy life years lost in Europe* | Report | Background information on environmental noise; exclude |
| **Submitted Literature** | | | | |
| Acoustic Ecology Institute | 2009 | *Wind turbine noise impacts* | Report | Background information on wind energy noise impact; exclude |
| Acoustic Ecology Institute (compiled by Jim Cummings) | 2011 | *Wind turbine noise: science and policy overview* | Report | Background information on policy for wind farming; exclude |
| Acoustic Group Pty Ltd, The | 2012 | *Review of Draft Wind Farm Guidelines 42.4963.R2:ZSC* | For Flyers Creek Wind Turbine Awareness Group Inc., 14 March 2012 | Background information on wind farm guidelines; exclude |
| Acoustic Group Pty Ltd, The | 2012 | *Peer Review of Noise Impact Assessment, Stony Gap Wind Farm 42.4989.R1:ZSC* | Prepared for Regional Council of Goyder, 26 May 2012 | Background information on acoustic assessment of a wind farm proposal; exclude |
| Adcock J, Delaire C, Griffen D | 2012 | A review of the Draft NSW Planning Guidelines: wind farms | *Acoustics Australia* 2012; 40:1 | Guidelines/regulations for wind farms; exclude |
| The Acoustic Ecology Institute | 2009 | *AEI Special Report: Wind energy noise impacts* | Available from <www.acousticecology.org> | Background information on wind energy noise impact; exclude |
| The Acoustic Ecology Institute | 2011 | *Wind farm noise 2011: science and policy overview* | Available from <www.acousticecology.org> | Background information on policy for wind farming; exclude |
| Alves-Pereira M, Castelo Branco NAA | 2007 | Vibroacoustic disease: biological effects of infrasound and low-frequency noise explained by mechanotransduction cellular signaling | *Progress in Biophysics and Molecular Biology* 2007; 93(1–3):256–279 | Background information on vibroacoustic disease; exclude |
| Alves-Pereira M, Castelo Branco NAA | 2007 | Public health and noise exposure: the importance of low-frequency noise | Proceedings of the InterNoise Conference, Istanbul, Turkey, pp. 3–20 | Background information on low-frequency noise impact; exclude |
| Alves-Pereira M, Castelo Branco NAA | 2011 | Low-frequency noise and health effects, June 2011 | Presented at the NHMRC forum Wind Farms and Human Health, 7 June 2011 | Background information on possible health effects of low-frequency noise; exclude |
| Alves-Pereira M, Castelo Branco NAA | 2007 | In-home wind turbine noise is conducive to vibroacoustic disease | Second International Meeting on Wind Turbine Noise, Lyon, France, 20–21 September 2007 | Background information on vibroacoustic disease; exclude |

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| Ambrose R | 2009 | | Letter to Carman Krogh Pharm | Commentary/opinion—letter; exclude |
| Ambrose SE, Rand RW, Krogh CME | 2012 | Wind turbine acoustic investigation: infrasound and low-frequency noise: a case study | *Bulletin of Science, Technology & Society*, doi: 10.1177/0270467612455734 | Study—does not include exposed population and health outcomes; exclude |
| Ambrose SE, Rand RW, Krogh CME | 2012 | Falmouth, Massachusetts wind turbine infrasound and low-frequency noise measurements | Presented at InterNoise 2012 19–22 August 2012, New York City | Background information on wind turbine noise measurement, no health outcomes; exclude |
| Ambrose SE, Rand RW, Krogh CME | 2012 | Industrial wind turbines and health: wind turbines can harm humans if too close to residents. A summary of some peer-reviewed and conference articles, their abstracts and citations, regarding adverse health effects and wind turbines | *Bulletin of Science Technology & Society,* published online 17 August 2012 | List of abstracts with no additional articles meeting inclusion criteria; exclude |
| Appelqvist P, Almgren M | 2011 | Wind turbine noise in sheltered dwelling areas | Fourth International Meeting on Wind Turbine Noise, Rome, Italy, 12–14 April 2011 | Not found by cut-off date; exclude |
| Australian Academy of Technological Sciences and Engineering (ATSE) | 2009 | The hidden costs of electricity: externalities of power generation in Australia | | Background information on cost of power generation; exclude |
| Babish W | 2011 | Cardiovascular effects of noise | Editorial commentary, *Noise Health* 2011; 13:201–204 | Background information on effects of noise on health; exclude |
| Baerwald EF, D'Amours GH, Klug BJ, Barclay RMR | 2008 | Barotrauma is a significant cause of bat fatalities at wind turbines | Department of Biological Sciences, University of Calgary, Calgary, in: *Current Biology* 2008; 18:16 | Study—unsuitable population; exclude |
| Bakker H, Bennett D, Rapley B, Thorne R | 2009 | Seismic effect in residents from 3 MW wind turbines | Presented at the Third International Meeting on Wind Turbine Noise, Aalborg, Denmark, 17–19 June 2009 | Background information on seismic effects of wind turbines in NZ, no health outcomes; exclude |
| Bakker H, Rapley B | 2010 | Sound characteristics of multiple wind turbines | *Sound, Noise, Flicker and the Human Perception of Wind Farm Activity*, pp. 233–258 | Background information on wind turbine sound; exclude |
| Bakker H, Bennett D, Rapley B, Thorne R | 2010 | Seismic effects on residents from wind turbines | Rapley and Bakker (eds) 2010, pp. 225–231 | Background information on seismic effects of wind turbines; exclude |
| Barrett N | 2012 | Getting the wind up: exploring the concern about | | Narrative review; exclude |

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| | | adverse health effects of wind power in Australia and Europe | | |
| Bartholomew R, Wessely S | 2002 | Protean nature of mass sociogenic illness: from possessed nuns to chemical and biological terrorism fears | *British Journal of Psychiatry* 2002; 180:300–306 | Background information only; exclude |
| Bartlett DJ, Marshall NS, Williams A, Grunstein RR | 2008 | Predictors of primary medical care consultation for sleep disorders | *Sleep Medicine* 2008; 9:857–864 | Background information only; exclude |
| Bengtsson J, Persson Waye K, Kjellberg A | 2004 | Sound characteristics in low-frequency noise and their relevance for the perception of pleasantness | *Acta Acoustica* 2004; 90:171–180 | Background information on low-frequency noise; exclude |
| Bengtsson J, Persson Waye K, Kjellberg A | 2004 | Evaluations of effects due to low-frequency noise in a low demanding work situation | *Journal of Sound and Vibration* 2004; 278:83–99 | Background information on low-frequency noise; exclude |
| Berglund B, Hassmen P, Job SR F | 1996 | Sources and effects of low-frequency noise | *Journal of the Acoustical Society of America* 1996; 99:2985–3002 | Background information on low-frequency noise; exclude |
| Bin YS, Marshall NS, Glozier N | 2012 | The burden of insomnia on individual function and healthcare consumption in Australia | *Australian and New Zealand Journal of Public Health* 2012; online doi: 10.1111/j.1753-6405.2012.00845.x | Background information only; exclude |
| Boss LP | 1997 | Epidemic hysteria: a review of published literature | *Epidemiological Review* 1997; 19(2) | Background information only; exclude |
| Bowdler D | 2008 | Amplitude modulation of wind turbine noise: a review of the evidence | *Acoustics Bulletin* 2008; 33(4) | Background information on technicalities of wind turbine noise; exclude |
| Bowdler D | 2012 | Wind turbine syndrome: an alternative view | Acoustics Australia 2012; 40(1) | Commentary/opinion paper; exclude |
| Bradley JS | 1994 | Annoyance caused by constant-amplitude and amplitude-modulated sound containing rumble | *Noise Control Engineering Journal* 1994; 42:203–208 | Background information on annoyance of noise; exclude |
| Bronzaft AL | 2011 | The noise from wind turbines: potential adverse impacts on children's well-being | *Bulletin of Science Technology & Society* 2011; 31:291 | Background information on wind turbine noise effects on children; exclude |
| Brooks D | | Peer-reviewed studies of wind turbine health impacts | | List of references, no additional articles for inclusion; exclude |
| Brooks D | 2012 | *NSW Planning Guidelines: wind farms: a resource for the community, applicants and consent authorities* (draft) | Submission to the NSW Department of Planning & Infrastructure<br>By Parkesbourne/Mummel Landscape Guardians Inc. | Guidelines/regulations on wind farm planning; exclude |

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| Brown County Board of Health | 2012 | Brown County Board of Health resolution requesting emergency state aid for families suffering around industrial wind turbines | | Commentary/opinion; exclude |
| Bruni O, Novelli L, Ferri R | 2011 | *Sleep disturbance and wind turbine noise* | Sapienza University, Rome, Italy and Institute for Research on Mental Retardation and Brain Aging, Troina, Italy | Background information on noise effects on children; exclude |
| Canadian Wind Energy Association | 2011 | Canadian Wind Energy Association responds to October 14 2011 statement by Wind Concerns Ontario | | Commentary/opinion, links to related wind farm documents; revealed no new references; exclude |
| Capuccio FP, Cooper D, D'Elia L, Strazzullo P, Miller MA | 2011 | Sleep duration predicts cardiovascular outcomes: a systemic review and meta-analysis of prospective studies | *European Heart Journal* 2011; 32(12):1484–1492; Epub 7 Feb 2011 | Background information only; exclude |
| Castelo Branco NAA, Alves-Pereira M | 2004 | Vibroacoustic disease | *Noise & Health* 6 (23), 320 | Background information only; exclude |
| Le Groupe de Travail | | Le retentissement du fonctionnment des eoliennes sur la sante de l'homme | Academie Nationale de Medecine | Language not English; exclude |
| Ceranna L, Hartmann G, Henger M | 2005 | The inaudible noise of wind turbines | Conference paper, Infrasound Workshop Nov 28 – Dec 02 2005, Tahiti (Federal Institute for Geosciences and Natural Resources) | Background information on wind turbine noise; exclude |
| Chao P, Yeh C, Juang Y, Hu C, Chen C | 2012 | Effect of low-frequency noise on the echocardiographic parameter E/A ratio | *Noise Health* 2012; 14:155–158 | Background information on the effects of low-frequency noise; exclude |
| Chapman S | 2011 | Wind farms and health: who is fomenting community anxieties? | *Medical Journal of Australia* 2011; 195(9) | Commentary/opinion; exclude |
| Chapman S | 2012 | Submission to NSW Wind Farm Guidelines | School of Public Health, University of Sydney | Narrative review; exclude |
| Chapman S, George A | 2006 | A disease in search of a cause: a study of self-citation and press release pronouncement in the factoid of wind farms causing 'vibroacoustic disease' | School of Public Health, University of Sydney | Background information on vibroacoustic disease; exclude |
| Chen HA, Narins P | | Wind turbines and ghost stories: the effects of infrasound on the human auditory system | | Background information on technical aspects of infra sound from wind turbines; exclude |

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| Chouard C-H | | Impacts of wind turbine operation on humans | National Academy of Medicine | Background information only; exclude |
| Comite senatorial permanent de l'energie, de l'environnement et des ressources naturelles | 2011 | Les eoliennes industrielles et la sante. Les eoliennes peuvent causer du tort aux humains | Le 18 octobre 2011 | Language not English; exclude |
| Cooper D | 2012 | Peer review of noise impact assessment, Stony Gap Wind Farm 42.4989.R1:ZSC | Prepared for Regional Council of Goyder, 26 May 2012 (The Acoustic Group Pty Ltd) | Background information on wind turbine noise assessment; exclude |
| da Fonseca J, dos Santos JM, Branco NC, Alves-Pereira M, Grande N, Oliveira P, Martins AP | 2006 | Noise-induced gastric lesions: a light and scanning electron microscopy study of the alterations of the rat gastric mucosa induced by low-frequency noise | *Central European Journal of Public Health* 2006; 14(1):35–38 | Study—unsuitable population; exclude |
| Davis J | 2007 | Noise pollution from wind turbines | Presented at the Second International Meeting on Wind Turbine Noise, Lyon, France | Commentary/opinion; exclude |
| Dean D | 2007 | Wind turbine mechanical vibrations: potential environmental threat | | Commentary/opinion—letter; exclude |
| Dean R | | Infrasound modulation of 1000 Hz one-third octave | | Background information only; exclude |
| DeGagne DC, Lapka SD | 2008 | Incorporating low-frequency noise legislation for the energy industry in Alberta, Canada | *Journal of Low Frequency Noise, Vibration and Active Control* 2008; 27(2):105–120 | Background information on measurement and legislation of low-frequency noise for the Canadian energy industry; exclude |
| Department of Planning and Community Development (Victoria) | 2011 | Policy and planning guidelines for development of wind energy facilities in Victoria, August 2011 | | Guidelines/regulations on policy and planning; exclude |
| Deutscher Akkreditierungs Rat | 2004 | Measurement of the acoustic noise emission of the IT 77/1500 CIII H80 wind turbine; Report no. DEWIS AM 138/04, 2004-07-23 | | Background information on noise measurement; exclude |
| Devine-Wright P | 2011 | Public engagement with large-scale renewable energy technologies: breaking the cycle of NIMBYism | WIREs Climate Change 2011; 2(1):19–26 | Background information on the public and renewable energy; exclude |
| Dickinson PJ | 2009 | Submission to Standards NZ 6808:2009 Acoustics – wind farm noise | | Discussion on NZ acoustic standards and characteristics wind farm noise; exclude |
| Dickinson PJ | 2009 | Nonsense on stilts | Proceedings of Acoustics 2009, 23–25 November 2009, Adelaide, | Testimonial submission to Standards NZ; exclude |

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| Dickinson PJ | 2010 | Sounds from wind turbines: theory, practice, assumptions and reality | In: Rapley and Bakker (eds) 2010), pp. 181–205 | Discussion only; exclude |
| Doolan CJ, Moreau DJ, Brooks LA | 2012 | Wind turbine noise mechanisms and some concepts for its control | *Acoustics Australia* 2012; 40(1) | Background information on turbine noise mechanism; exclude |
| Ecker LS, Ullrich KH, Seifert CM, Schwarz N, Cook J | 2012 | Misinformation and its correction: continued influence and successful debiasing | *Psychological Science in the Public Interest* 2012; 13:3106–3131 | Background information only; exclude |
| Elliott SJ | 2005 | Feedback control of engineering structures and in the inner ear | Forum Acusticum 2005, Budapest | Background information only; exclude |
| Environment Protection Authority (NSW) | 2000 | *NSW Industrial Noise Policy, January 2000* | Retrieved from <www.environment.nsw.gov.au/ noise/industrial.htm> | Background information on industrial noise policy; exclude |
| Environment Protection Authority (South Australia) | 2009 | *Wind farms environmental noise guidelines*, July 2009 | | Background information on guidelines for wind farms; exclude |
| Environmental review tribunal | 2011 | Erickson Vv, Director, Ministry of the Environment | | Court proceedings; exclude |
| Etherington J | 2009 | *The wind farm scam: an ecologist's evaluation* | Stacey International, 2009 | Commentary/opinion; exclude |
| Falmouth Board of Health | 2012 | Health effects of wind turbines | | Summary of testimonial submissions; exclude |
| Falmouth Health Department | 2012 | Request that Mass DPH immediately initiate a health assessment of the impacts of the operation of wind turbines in Falmouth | Letter to Ms Condon | Commentary/opinion paper; exclude |
| Feldmann J, Pitten FA | 2004 | Effects of low-frequency noise on man: a case study | *Noise Health* 2004;7:23–28 | Background information on infrasound; exclude |
| Findeis H, Peters E | 2004 | Disturbing effects of low-frequency sound immissions and vibrations in residential buildings | *Noise Health* 2004;6:29–35 | Background information on low-frequency sound; exclude |
| French Academy of Medicine | 2006 | Repercussions of wind turbine operations on human health | <http://ventdubocage.net/documentsoriginaux/sante/eoliennes.pdf > | Language not English; exclude |
| Frey BJ, Hadden PJ | 2007 | Noise radiation from wind turbines installed near homes | | Narrative review on wind turbine noise and health; exclude |
| Friends of Collector Inc. | 2012 | Submission to the New South Wales Department of Planning and Infrastructure 'NSW Planning | Mr Tony Hodgson, Inaugural President, Friends of Collector | Salt, McMurty and Cooper papers—background information only; Wang study— |

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| | | Guidelines -Windfarms' | Inc. | see Wang V entry; exclude all |
| Friends of Collector Inc. | 2011 | Submission to the Senate Community Affairs Committee Inquiry into the Social and Economic Impacts of Rural Wind Farms | Mr Tony Hodgson, Inaugural President, Friends of Collector Inc. | Background information on wind farm impacts on health; exclude |
| Geen RG, McCown EJ | 1984 | Effects of noise and attack on aggression and physiological arousal | *Motivation and Emotion* 1984; 8:231–241 | Background information only; exclude |
| Genuit K | 2007 | Tiefe Frequenzen sind nicht gleich tiefe Frequenzen – Tieffrequente Geräuschanteile und deren (Lärm-)Wirkungen. (LFN does not equal LFN – LF components of sound and their effects (on man) | HEAD acoustics GmbH; conference paper – DAGA 2007 | Language not English; exclude |
| Gillespie EK | 2011 | WPD (White Pines Project), Prince Edward County, Ontario (the 'Project') | Letter to Mr K Surette, WPD, Canada, 8 November 2011 | Commentary/opinion—letter; exclude |
| Gillespie EK | 2011 | Ministry of the Environment webpage: 'The sound of science' | Letter to various recipients, 23 November 2011 | Commentary/opinion—letter; exclude |
| Gillespie EK | 2012 | Ministry of the Environment Media Release 'Expert report Confirms no direct health effects from wind turbines' | Letter to various recipients, 3 January 2012 | Commentary/opinion—letter; exclude |
| Grewal T, James C, Macefield VG | 2011 | Frequency-dependent modulation of muscle sympathetic nerve activity by sinusoidal galvanic vestibular stimulation in human subjects | *Journal of Occupational and Environmental Medicine* 2011; 53(2):146–152 | Background information only; exclude |
| Griefahn B, Basner M | 2011 | Disturbances of sleep by noise | Paper no. 107, Proceedings of Acoustics 2011, 2–4 November 2011, Gold Coast, Australia | Background information on sleep disturbance; exclude |
| Gueniot C. | 2006 | Le retentissement du fonctionnement des éoliennes sur la santé de l'homme ('Repercussions of wind turbine operations on human health') | Wind turbines: The Academy cautious, Panorama du médecin, 20 March 2006, reporting on National Academy of Medicine in France | Language not English; exclude |
| Guest M, Boggess M, D'Este C, Attia J, Brown A | 2011 | An observed relationship between vestibular function and auditory thresholds in aircraft-maintenance workers | School of Health Sciences, University of Newcastle, Australia, *Journal of Occupational and Environmental Medicine* 2011; 53(2):146–152 | Background information only; exclude |

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| Hansen C | 2010 | Assessment of noise from the proposed wind farm development around Mt Bryan, near the township of Hallett | Prepared for Environment, Resources and Development Court, SA, by School of Mechanical Engineering, University of Adelaide, South Australia | Not found by cut-off date; exclude |
| Hanning C | 2010 | Sleep disturbance and wind turbine noise | On behalf of the Northumberland & Newcastle Society | Narrative review; exclude |
| Hanning C | 2012 | Wind turbine noise, sleep and health | Response to: The Northumberland County Council Core Issues and Options Report Consultations | Narrative review; exclude |
| Hanning CD, Evans A | 2012 | Wind turbine noise (editorial) | *British Medical Journal* 2012; 344:e1527 doi: 10.1136/bmj.e1527 (published 8 March 2012) | Commentary/opinion—editorial; exclude |
| Harding G, Harding P, Wilkins A | 2008 | Wind turbines, flicker and photosensitive epilepsy: characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them | *Epilepsia* 2008; 49(6):1095–1098 | Background information on wind turbine flicker; exclude |
| Harrison J P | 2011 | Wind turbine noise | *Bulletin of Science, Technology & Society* 2011; 31:256–261 | Background information on wind turbine noise; exclude |
| Hatfield J, Job RF, Hede AJ, Carter NL, Peploe P, Taylor R et al. | 2002 | Human response to environmental noise: the role of perceived control | *Journal of Behavioural Medicine* 2002;9:341–359 | Background information on environmental noise; exclude |
| Hauser W, Hansen E, Enck P | 2012 | Nocebo phenomena in medicine | *Deutsches Arztblatt International* 2012; 109(26):459–465 | Background information only; exclude |
| Havas M, Colling D | 2011 | Wind turbines make waves: why some residents near wind turbines become ill | Published online before print 30 September 2011, doi: 10.1177/0270467611417852; *Bulletin of Science, Technology & Society* 2011; 31:414–426 | Background information on possible health associations with wind turbines; exclude |
| Health Canada | 2009 | Health Canada's response to the Digby Wind Power Project Addendum, Digby, Nova Scotia | Email correspondence to Mr Sanford, 6 August 2009 | Commentary/opinion—letter; exclude |
| Health Canada | 2010 | Useful information for environmental | | Background information only; exclude |

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| | | assessments | | |
| Health Canada | 1986 | *Achieving health for all: a Framework for health promotion* | Webpage | Background information only; exclude |
| Health Canada | 2012 | *Community noise annoyance* | Copy of webpage | Background information only; exclude |
| Health Canada | 2009 | *Mental health: anxiety disorders* | Fact sheet | Background information only; exclude |
| Health Canada | 2012 | *Mental health* | Copy of webpage | Background information only; exclude |
| Health Canada | 2008 | *Mental health: coping with stress* | Fact sheet | Background information only; exclude |
| Hegarty & Elmgree Lawyers | 2012 | Wind farms and human health | Letter to Profs Anderson and McCallum acting on behalf of Friends of Collector Inc. | Commentary/opinion—letter; exclude |
| Horner B | 2012 | Open letter audit: National Health and Medical Research Council updated literature review and NHMRC updated public statement | Letter to Profs Anderson and McCallum at the NHMRC, and Dr Bruce Armstrong, University of Sydney | Commentary/opinion—letter; exclude |
| Horner B | 2012 | Comment on the 'Wind Turbine Impact Study: Report of independent expert panel, January 2012, prepared for Massachusetts Department of Environment Protection, Massachusetts Department of Public Health' | | Commentary/opinion—letter; exclude |
| Horner B, Jeffery RD, Krogh CME | 2011 | Literature reviews on wind turbines and health: are they enough? | *Bulletin of Science Technology & Society* 2011; 31:399 | Background information on effectiveness of literature reviews of the health effects of wind turbines; exclude |
| Howe Gastmeier Chapnik Limited | 2010 | Low-frequency noise and infrasound associated with wind turbine generator systems: a literature review. | Ontario Ministry of the Environment RFP no. OSS-078696 | Background information on wind turbine noise; exclude |
| Hubbard HH, Shepherd KP | 1990 | *Wind turbine acoustic* | NASA Technical Paper 3057 DOE/NASA/20320-77 | Background information on wind turbine acoustics; exclude |
| Hygge S | 2011 | Noise and cognition in children | University of Gävle, Gävle, Sweden, Elsevier BV | Background information only; exclude |
| IBM Consulting Services | 2002 | Traffic noise outside the home POR-02-65-S | Health*Insider* 2002 | Background information only; exclude |
| Independent Australia | 2012 | Study shows why misinformation works | <http://www.independentaustralia.net/2012/environment/why-misinformation-works/> | Background information only; exclude |
| Institute for Clinical Evaluative Sciences, Public | 2012 | *Seven more years: the impact of smoking, alcohol, diet, physical activity and stress on* | Report | Background information only; exclude |

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| Health Ontario | | *health and life expectancy in Ontario* | | |
| Intergovernmental Panel on Climate Change | 2012 | *Renewable energy sources and climate change mitigation* | | Background information only; exclude |
| Inukai Y, Taya H, Yamada S | 2005 | Thresholds and acceptability of low-frequency pure tones by sufferers | *Journal of Low Frequency Noise, Vibration and Active Control* 2005; 24(3):163–169, doi:10.1260/026309205775374433 | Background information on low-frequency sound; exclude |
| Iser D | 2004 | Local wind farm survey | Dr David Iser's findings at Toora, Victoria, 2004 | Study—case series, no comparative analysis; exclude |
| Ising H, Lange-Asschenfeldt H, Moriske H, Born J, Eilts M | 2004 | Low-frequency noise and stress: bronchitis and cortisol in children exposed chronically to traffic noise and exhaust fumes | *Noise Health* 2004; 6:21–28 | Background information on low-frequency noise and health effects; exclude |
| James RR | 2012 | Wind turbine infra- and low-frequency sound: warning signs that were not heard | *Bulletin of Science, Technology & Society* 2012; 32(2):108–127 | Background information on wind turbine low-frequency and infrasound; exclude |
| Johansson M | 2012 | Speech at the General Meeting of Vestas | Thursday 29 March 2012, Aarhus Concert Hall | Commentary/opinion; exclude |
| Jones, GP, Lukashkina, VA, Russell, IJ, Lukashkin, AN | 2010 | The vestibular system mediates sensation of low-frequency sounds in mice | *Journal of the Association for Research in Otolaryngology*, 2010; 11(4):725–732 | Study—unsuitable population; exclude |
| Jung SS, Cheung W | 2008 | Experimental identification of acoustic emission characteristics of large wind turbines with emphasis on infrasound and low-frequency noise | *Journal of Korean Physical Society*; 53:1897–1905 | Background information on wind turbine low-frequency noise and infrasound; exclude |
| Kaiser-Wilhelm-Koog GmbH | 2006 | WINDTEST | Report of acoustical emissions of a wind turbine generator system type Acciona AW 82/1500 IEC lllb T80A LM40.3P in the Moncayuelo wind farm in Spain | Background information only; exclude |
| Kamp F, Sottek R, Fiebig A | 2012 | Lautheitswahrnehmung von tieffrequenten Schallen (Perception of loudness of low-frequency sounds) | HEAD acoustics GmbH; Conference paper, DAGA 2012 | Language not English; exclude |
| Kasprzak C | | The influence of infrasounds on the electrocardiograph patterns in humans | *Acoustic and Biomedical Engineering* 2010; 118(1) | Background information on effects of infrasound; exclude |
| Keith SE, Michaud DS, Bly SHP | 2008 | A proposal for evaluating the potential health of wind turbine noise for projects under the | *Journal of Low Frequency Noise, Vibration and Active Control* | Background information on wind turbine noise evaluation; exclude |

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| | | Canadian Environmental Assessment Act | 2008; 27(4):253–265 | |
| Kemp AJ | 2010 | Written correspondence with medical opinion | Medical information evidence of non-compliance | Commentary/opinion—letter; exclude |
| Knopper LD, Ollson C | 2011 | Health effects and wind turbines: a review of the literature | *Environmental Health* 2011; 10:78 <http://www.ehjournal.net/content/10/1/78> | Narrative review; exclude |
| Krahé D. | 2008 | Why is sharp-limited low-frequency noise extremely annoying? | Conference paper, Acoustics08, Paris, June 29 – July 4 2008 | Background information only; exclude |
| Krogh CME | 2010 | A gross Injustice | Paper presented to the First International Symposium on Adverse Health Effects from Wind Turbines, Picton, Ontario, 29–31 October 2010 | Commentary/opinion; exclude |
| Krogh CME | 2012 | Adverse health effects and industrial wind turbines | Letter to Profs Anderson and McCallum at the NHMRC | Commentary/opinion—letter; exclude |
| Krogh CME | 2011 | Industrial wind turbine development and loss of social justice? | *Bulletin of Science Technology & Society* 2011; 31:321 | Background information on social justice and wind energy; exclude |
| Krogh CME | 2012 | Notice to stakeholders: Health Canada Wind Turbine Noise and Health Study | Letter to Prime Minister Stephen Harper, Office of the Prime Minister, Ottawa | Commentary/opinion—letter; exclude |
| Krogh CME, Gillis L, Kouwen N | 2011 | A self-reporting survey of adverse health effects associated with industrial wind turbines: the need for vigilance | WindVOICE - Wind Vigilance for Ontario Communities | Study; **include** |
| Krogh CME, Horner B | 2012 | Open letter; peer review; Health Canada Wind Turbine Noise and Health Study | | Narrative review; exclude |
| Krogh CME, Jeffery RD, Aramini J, Horner B | 2012a | Wind turbine noise perception, pathways and effects: a case study | Inter-Noise Congress, 19–22 August 2012, New York City | Background information on wind turbine noise perception; exclude |
| Krogh CME, Jeffery RD, Aramini J, Horner B | 2012b | Annoyance can represent a serious degradation of health—wind turbine noise: a case study | Inter-Noise Congress, 19–22 August 2012, New York City | Background information on wind turbine noise and annoyance; exclude |
| Krogh CME, Jeffery RD, Aramini J, Horner B | 2012c | Wind turbines can harm humans: a case study | Inter-Noise, 19–22 August 2012, New York City | Background information only; exclude |
| Laurie S | 2010 | Blood pressures elevating dangerously after night-time wind turbine exposure (Australia) | <www.windturbinesyndrome.com/news/> | Background information on wind turbine syndrome; exclude |
| Leake J, Byford H | 2009 | Officials cover up wind farm noise report | *The Sunday Times*, 13 December | Commentary/opinion; exclude |

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| Legislative Assembly of Ontario | 2009 | Official Report of Debates (Hansard), Standing Committee on General Government; Green Energy and Green Economy Act 2009 | | Background information only; exclude |
| Leventhall G | 2006 | Infrasound from wind turbines: fact, fiction or deception | *Canadian Acoustics* 2006; 34(2): 29 | Background information on wind turbine infrasound; exclude |
| Leventhall G | 2005 | How the 'mythology' of infrasound and low-frequency noise related to wind turbines might have developed | First International Meeting on Wind Turbine Noise: Perspectives for Control, Berlin 17–18 October 2005 | Commentary/opinion; exclude |
| Leventhall G | 2009 | Wind turbines: large, small and unusual | Presentation | Background information only; exclude |
| Leventhall G | 2009 | Wind turbine syndrome: an appraisal | | Commentary/opinion; exclude |
| Leventhall G | 2011 | Wind farms and human health | Presentation | Background information only; exclude |
| Leventhall G, Pelmear P, Benton S | 2003 | A review of published research on low-frequency noise and its effects | Department of the Environment, Food and Rural Affairs, Defra Publications, London, England | Background information on low-frequency noise; exclude |
| Maruyama Y | | Noise issue report | | Language not English; exclude |
| Maruyama Y | | Capacity x distance | | Language not English; exclude |
| Maschke C, Niemann H | 2007 | Health effects of annoyance induced by neighbour noise | *Noise Control Engineering Journal* 2001; 55(3):348–356(9) | Background information on annoyance caused by noise; exclude |
| McBride D, Rapley B | 2010 | Blade flicker, shadow flicker, glint: potential hazards of wind turbines | Rapley and Bakker (eds) 2010, pp. 79–92 | Background information on potential impacts of wind turbines; exclude |
| McMurtry R | 2011 | Appendix C: Evidence of known adverse health effects to industrial wind turbines | Submitted to the Appeal for Renewable Energy Approval issued to Kent Breeze Corp. and MacLeod Windmill Project Inc. (Kent Breeze Wind Farms) c/o Suncor Energy Services Inc., EBR Registry Number 011-1039 Chatham-Kent, 16 January 2011 | Narrative review; exclude |
| McMurtry R, Nissenbaum MA, Hanning C, Jeffery RD, Harrison J, James R, White DL, Horner B, Harrington B, Krogh CME | 2010 | A primer on adverse health effects and industrial wind turbines, March 2010 | Prepared by the Society for Wind Vigilance <www.windvigilance.com/primer_ahe.aspx> | Commentary/opinion; exclude |

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| McMurtry R, Nissenbaum MA, Hanning C, Jeffery RD, Harrison J, James R, White DL, Horner B, Harrington B, Krogh CME | 2010 | Haste makes waste: an analysis of the National Health and Medical Research Council's *Wind turbines and health, a Rapid review of the evidence*, July 2010' | Prepared for the Society for Wind Vigilance | Background information—discussion and analysis of the NHMRC 2010 rapid review; exclude |
| McMurtry RY | 2011 | Toward a case definition of adverse health effects in the environs of industrial wind turbines: facilitating a clinical diagnosis | *Bulletin of Science Technology and Society* 2011; 31:316 | Background information on how to define health effects of wind turbines; exclude |
| Mechanical Engineering Testing & Consulting | 2010 | Assessment of noise from the proposed wind farm development around Mt Bryan, near the township of Hallett | Prepared for Environment, Resources and Development Court, SA, by School of Mechanical Engineering, University of Adelaide, South Australia | Background information on wind farm noise assessment; exclude |
| Michaud DS, Bly SHP, Keith SE | 2008 | Using a change in percentage highly annoyed with noise as a potential health effect measure for projects under the Canadian Environmental Assessment Act | *Canadian Acoustics* 2008; 36(2):13–28 | Background information on noise annoyance as a health effect; exclude |
| Michaud DS, Keith SE, McMurchy D | 2005 | Noise annoyance in Canada | *Noise & Health* 2005; 7(27):39–47 | Background information on noise annoyance as a health effect; exclude |
| Michaud DS, Keith SE, McMurchy D | 2007 | A proposal for evaluating the potential health of wind turbine noise for projects under the Canadian Environmental Assessment Act | Second International Meeting on Wind Turbine Noise, Lyon, France, 20–21 September 2007 | Background information on wind turbine noise evaluation; exclude |
| Mirowska M, Mroz E | 2000 | Effect of low-frequency noise at low levels on human health in light of questionnaire investigation | *Proceedings of Inter-Noise Congress* 2000; 5:2809–2812 | Background information on low-frequency noise and human health; exclude |
| Moller H, Pedersen CS | 2011 | Low-frequency noise from large turbines | Section of Acoustics, Aalborg University; *J Acoustical Society America* 2011; 129:3727–3744 | Background information on noise description of wind turbines ; exclude |
| Moller H, Pedersen CS | 2004 | Hearing at low and infrasonic frequencies | *Noise and Health* 2004; 6(23):37–57 | Background information only; exclude |
| Moller H, Pedersen CS | 2011 | Low-frequency wind turbine noise | *Journal of the Acoustical Society of America* 2011; 129(6):3725–3743 | Background information on noise description of wind turbines; exclude |
| Morris M | 2012 | Waterloo Wind Farm Survey | | Links 2,3 and 4 opinion papers/letters only; |

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| | | | | exclude. Link 1 included for additional data to Morris 2012 Survey. |
| Morris M | 2012 | Waterloo Wind Farm Survey April 2012: Part 2—Graphs | This document is to be read in conjunction with 'Waterloo Wind Farm Survey April 2012 – Select Committee' by M Morris | Study; **include** |
| New South Wales Landscape Guardians Inc. | 2011a | What is wrong with the current noise assessment for wind turbines in NSW? July 2011 | | Commentary/opinion; exclude |
| New South Wales Landscape Guardians Inc. | 2012 | Submission to Health Canada regarding Health Canada Wind Turbine Noise and Health Study, August 2012 | | Not found by cut-off date; exclude |
| New South Wales Landscape Guardians, Inc. | 2011b | Grounds for an appeal against NSWLEC 59 [2007] and NSWLEC 1102 [2010], the Taralga and Gullen Range Wind Farm Cases, August 2011 | | Commentary/opinion; exclude |
| New South Wales. Parliament, Legislative Council; General Purpose Standing Committee No. 5 | 2009 | Rural wind farms | | Background information on legislation for wind farm projects; exclude |
| New South Wales. Parliament, Legislative Council; General Purpose Standing Committee No. 5 | 2009 | Inquiry into rural wind farms | Media release, Wednesday 16 December 2009 | Commentary/opinion; exclude |
| NHS Choices | 2010 | Wind turbine sound 'needs research' | NHS Knowledge Service 28, January 2010 | Commentary/opinion; exclude |
| Niemann H, Bonnefoy X, Braubach M, Hecht K, Maschke C, Rodrigues C, Robbel N. | 2006 | Noise-induced annoyance and morbidity results from the pan-European LARES study | *Noise Health* 2006; 8:63–79 | Background information on annoyance caused by noise; exclude |
| Niemann H, Maschke C | 2004 | WHO LARES: report on noise effects and morbidity | | Background information on noise and morbidity; exclude |
| Nissenbaum MA | 2010 | Wind turbines, health, ridgelines and valleys | | Duplicate study/data—an updated version identified and included (Nissenbaum, Aramini, Hanning 2012); exclude |
| Nissenbaum MA | 2009 | Mars Hill Wind Turbine Project health effects: preliminary findings | Presentation to Maine Medical Association, March 2009 | Preliminary study data presented in PowerPoint, with no comparative analysis; |

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| Nissenbaum MA, Aramini JJ, Hanning CD | 2011 | Adverse health effects of industrial wind turbines: a preliminary report | Conference paper, 10th International Congress on Noise as a Public Health Problem (ICBEN) 2011, London, UK | Duplicate study/data—an updated version identified and included (Nissenbaum, Aramini, Hanning 2012); exclude |
| Nissenbaum MA, Aramini JJ, Hanning CD | 2012 | Effects of industrial wind turbine noise on sleep and health | *Noise & Health* 2012; 14(60):237–43 | Study; **include** |
| Nobbs B, Doolan CJ, Moreau DJ | 2012 | Characterisation of noise in homes affected by wind turbine noise | Australian Acoustical Society | Background information on characterisation of wind turbine noise; exclude |
| Noise Association, The (UK) | 2009 | Location, location, location: an investigation into wind farms and noise by the Noise Association | <http://windconcernsontario.files.wordpress.com/2009/07/ukna-windfarmreport.pdf> | Background information on wind turbine location impact; exclude |
| Ogido R, Costa EA, Machado Hda C | 2009 | Prevalence of auditory and vestibular symptoms among workers exposed to occupational noise | Departamento de Medicina Preventiva e Social, Universidade Estadual de Campinas, Campinas, SP, Brazil; *Revista de Saude Publica* 2009; 43(2):377–380 | Language not English; exclude |
| O'Neal RD, Hellweg RD Jr, Lampeter RM | 2011 | Low-frequency noise and infrasound from wind turbines | *Noise Control Engineering* 2011; 59(2) | Background information on wind farm measurements and guidelines; exclude |
| Ontario Ministry of Health | 2011 | *Open minds, healthy minds: Ontario's comprehensive mental health and addictions strategy* | | Background information only; exclude |
| Ontario Ministry of Health | 2010 | *Health, not health care: changing the conversation* | 2010 Annual Report of the Chief Medical Officer of Health of Ontario and the Legislative Assembly of Ontario | Background information only; exclude |
| Ontario Ministry of the Environment | | Sound level adjustments | Publication NPC-104 | Background information only; exclude |
| Palmer W | | Learning from evidence of sound experienced from wind turbines | | Commentary/opinion; exclude |
| Papadopoulos G | 2012 | Wind turbines and low-frequency noise: implications for human health | | Commentary/opinion; exclude |
| Park J, Robertson J | 2009 | A portable infrasound generator | Infrasound Laboratory, University of Hawaii, 2009 Acoustical Society of America; | Background information only; exclude |

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| | | | doi: 10.1121/1.3093797 | |
| Parkesbourne/Mummel Landscape Guardians Inc. | 2012 | NSW Planning Guidelines—Wind farms: a resource for the community, applicants and consent authorities (draft) | Submission to the NSW Department of Planning & Infrastructure, March 2012 | Guidelines/ regulations; exclude |
| Pedersen E | 2010 | Health aspects associated with wind turbine noise: results from three field studies | *Noise Control Engineering Journal* 2010; 59(1):47–53 | Study; **include** (also identified in the black literature search) |
| Pedersen E, Hallberg LRM, Persson Waye K | 2007 | Living in the vicinity of wind turbines: a grounded theory study. | *Qualitative Research in Psychology* 2007; 4(1):49–63 | Study—qualitative design; exclude |
| Pedersen E, Larsman P | 2008 | The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines | *Journal of Environmental Psychology* 2008; 28:379–389 | Study; **include** (also identified in the black literature search) |
| Pedersen E, Persson Waye K | 2004 | Perception and annoyance due to wind turbine noise—a dose-response relationship. | *Journal of the Acoustical Society of America* 2004; 116(6):3460–3470 | Study; **include** (also identified in the black literature search) |
| Pedersen E, Persson Waye K | 2007 | Wind turbine noise, annoyance and self-reported health and well-being in different living environments | *Occupational and Environmental Medicine* 2007; 64(7):480–486 | Study; **include** (also identified in the black literature search) |
| Pedersen TH, Nielsen KKS | 1994 | Annoyance by noise from wind turbines | Report no. 150, DELTA Acoustic and Vibration, Lydtekniske Institute, Copenhagen [in Danish] | Language not English; exclude |
| Persson Waye K | 2004 | Effects of low-frequency noise on sleep | *Noise Health* 2004; 6:87–91 | Background information on low-frequency noise and sleep; exclude |
| Persson Waye K, Rylander R | 2001 | The prevalence of annoyance and effects after long-term exposure to low-frequency noise | *Journal of Sound and Vibration* 2001; 240(3):483–497 | Background information on low-frequency noise and annoyance; exclude |
| Persson Waye K, Rylander R, Benton S, Leventhall HG | 1997 | Effects on performance and work quality due to low-frequency ventilation noise | *Journal of Sound and Vibration* 1997; 205(4):467–474 | Background information on noise and work performance; exclude |
| Persson Waye K, Bengtsson J, Rylander R, Hucklebridge F, Evans P, Chow A | 2002 | Low-frequency noise enhances cortisol among noise sensitive subjects | *Life Sciences* 2002; 70:745–758 | Background information on health effects of low-frequency noise; exclude |
| Persson Waye K, Bengtsson J, Kjellberg A, Benton S | 2001 | Low-frequency noise 'pollution' interferes with performance | *Noise Health* 2001; 4:33–49 | Background information on low-frequency noise; exclude |
| Persson Waye K, Clow A, Edwards S, Hucklebridge F, | 2003 | Effects of night time low-frequency noise on the cortisol response to awakening and subjective | *Life Sciences* 2003; 72:863–875 | Background information on low-frequency noise and sleep; exclude |

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| and Rylander R | | sleep quality | | |
| Philips CV | 2011 | Properly interpreting the epidemiologic evidence about the health effects of industrial wind turbines on nearby residents | Populi Health Institute, Wayne, PA, USA; *Bulletin of Science, Technology & Society* 2011; 31:303–315; doi:10.1177/0270467611412554 | Background information on interpretation of health effects of wind turbines; exclude |
| Phillips CV | 2011 | Submission to the Australian Senate by CV Phillips on 'the health effects of wind turbines on nearby residents' re the social and economic impact of rural wind farms, 9 February 2011 | | Commentary/opinion; exclude |
| Phipps R | 2007 | Evidence of Dr Robyn Phipps, In the Matter of Moturimu Wind Farm Application, heard before the Joint Commissioners, 8–26 March, 2007, Palmerston North, NZ | | Commentary/opinion; exclude |
| Pierpont N | 2010 | Wind turbine syndrome and the brain | Conference paper, First International Symposium on the Global Wind Industry and Adverse Health Effects: Loss of social justice?, Picton, Ontario, Canada, 30 October 30 2010 | Background information on wind turbine syndrome; exclude |
| Pierpont N | 2007 | | Letter to Geoff Leventhall, Consultant in Noise and Vibration and Acoustics, 14 January 2007 | Commentary/opinion—letter; exclude |
| Punch J, James R, Pabst D | 2010 | Wind turbine noise: what audiologists should know | *Audiology Today* 2010; July/August issue | Background information on wind turbine noise; exclude |
| PWC Consulting | 2002 | Noise proprietary questions for Health Canada | Health*Insider* 2002; 7 | Background information only; exclude |
| Radneva R | 1997 | Studying the effect of acoustic conditions in the living environment of multifamily buildings on inhabitants (Bulg.) | *Khig. Zdraveopazvane* 1997; 40(3–4):40–44 EMBASE record 1998252323 | Background information on built environment acoustics; exclude |
| Rand RW, Ambrose SE, Krogh CME | 2011 | Occupational health and industrial wind turbines: a case study | Published online, doi: 10.1177/0270467611417849, *Bulletin of Science, Technology & Society* 2011; 31:359–362 | Commentary/opinion—sound measurements and personal experience of symptoms at an individual home near a turbine; exclude |

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| Rapley B, Bakker H (editors) | 2010 | Sound, noise, flicker and the human perception of wind farm activity | Atkinson & Rapley Consulting Ltd (Palmerston North, New Zealand), in association with Noise Measurement Services Pty Ltd (NMS) (Brisbane, Australia) | Background information, book requiring payment; exclude |
| Rideout K, Copes R, Bos C | 2010 | Wind turbines and health: evidence review | National Collaborating Centre for Environmental Health (Canada) | Background information only; exclude |
| Rider CV, Dourson M, Hertzberg RC, Mumtaz MM, Price PS, Simmons JE | 2012 | Incorporating Nonchemical Stressors into Cumulative Risk Assessment | *Toxicological Sciences Advance Access*; published 17 February 2012 | Background information only; exclude |
| Robert Koch Institute | 2007 | Infraschall und tieffrequenter Schall: ein Thema für den umweltbezogenen Gesundheitsschutz in Deutschland? (Subsonic low-frequency sound: a topic for the environmentally related health protection?) | *Bundesgesundheitsbl – Gesundheitsforsch – Gesundheitsschutz* 2007; 50:1582–1589 | Language not English; exclude |
| Roberts M, Roberts J | 2009 | *Evaluation of the scientific literature on the health effects associated with wind turbines and low-frequency sound* | Prepared for Wisconsin Public Service Commission Docket No. 6630-CE-302 | Narrative review; exclude |
| Salt AN | 2004 | Acute endolymphatic hydrops generated by exposure of the ear to non-traumatic low-frequency tone | *Journal of the Association of Research in Otolaryngology* 2004; 5:203–214 | Background information on effects of low-frequency sound; exclude |
| Salt AN | 2010 | *Wind turbines are hazardous to human health* | <www.oto2.wustl.edu/cochlea/wind.html> and at <www.windvigilance.com> | Background information on wind turbine infrasound; exclude |
| Salt AN, Hullar TE | 2010 | Responses of the ear to low-frequency sounds, infrasound, and wind turbines | *Hearing Research* 2010; 268(1–2):12–21 | Background information on effects of infrasound and low-frequency noise from wind turbines; exclude |
| Salt AN, Lichtenhan JT | 2011 | Responses of the inner ear to infrasound | Fourth International Meeting on Wind Turbine Noise, Rome, Italy, 12–14 April 2011 | Background information on effects of infrasound; exclude |
| Salt AN, Lichtenhan JT | 2012 | Perception-based protection from low-frequency sounds may not be enough | Inter-Noise Congress, 19–22 August 2012, New York City | Background information on effects of low-frequency sound; exclude |
| Schust M | 2004 | Effects of low-frequency noise up to 100 Hz | *Noise & Health* 2004; 6 23):73–85 | Background information on effects of low-frequency sound; exclude |
| Senanayake MP | 2002 | Noise from power generators: its impact on the | *Sri Lanka Journal of Child Health* | Background information only; exclude |

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| | | health of five children below two years of age | 2002; 31:115–117 | |
| Senate, The; Community Affairs References Committee | 2011 | *The social and economic impact of rural wind farms*, June 2011 | | Background information with no health outcomes; exclude |
| Sennheiser J | 2011 | The city and its secret vibrations | | Commentary/opinion; exclude |
| Shepherd D | 2012 | Wind farms and health: who is fomenting community anxieties? | *Medical Journal of Australia* 2012; 196(2) | Commentary/opinion—letter; exclude |
| Shepherd D | 2010 | Wind turbine noise and health in the New Zealand context | Rapley and Bakker (eds) 2010, pp. 15–68 | Background information only; exclude |
| Shepherd D | 2010 | | Submission by Daniel Shepherd, Auckland University of Technology | Background information and review; exclude |
| Shepherd D, Billington R | 2011 | Mitigating the acoustic impacts of modern technologies: acoustic, health and psychosocial factors informing wind farm placement | *Bulletin of Science Technology & Society* 2011; 31:389, originally published online 22 August 2011 | Background information on acoustic impact of technology; exclude |
| Shepherd D, Hanning C, Thorne B | 2012 | Noise: windfarms | | Background information on wind farm noise; exclude |
| Shepherd KP, Hubbard HH | 1989 | *Noise radiation characteristics of the Westinghouse WWG-0600 (600 kW) wind turbine generator* | National Aeronautics and Space Administration, TM101576, July 1989 | Background information only; exclude |
| Simonetti T, Chapman S | 2012 | Is there any disease or symptom NOT caused by wind turbines? | | List of symptoms with related weblinks, no additional references to include; exclude |
| Siponen D | 2011 | The assessment of low-frequency noise and amplitude modulation of wind turbines | Conference paper, 4th International Meeting on Wind Turbine Noise, Rome, Italy, 12–14 April 2011 | Background information on assessment of low-frequency noise from wind turbines; exclude |
| Smedley ARD, Webb AR, Wilkins AJ | 2010 | Potential of wind turbines to elicit seizures under various meteorological conditions | *Epilepsia* 2010; 51(7):1146–1151 | Background information of modelling for linking epileptic seizures to turbine shadow flicker; exclude |
| Society for Wind Vigilance | 2010a | *Wind energy industry acknowledgement of adverse health effects*: an analysis of the American/Canadian Wind Energy Association-sponsored wind turbine sound and health effects: an expert panel review, December 2009 | Prepared by the Society for Wind Vigilance, January 2010 | Background information only; exclude |

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| Society for Wind Vigilance | 2010b | *Delay, denial and disappointment*: an analysis of the Chief Medical Officer of Health (CMOH) of Ontario's 'The potential health impacts of wind turbines', May 2010 | Prepared by the Society for Wind Vigilance, 3 June 2010 | Background information and analysis of CMOH of Ontario review; exclude |
| Sonus Pty Ltd | 2010 | *Wind farms technical paper: environmental noise* | Prepared for the Clean Energy Council, November 2010, S3387C6 | Background information on wind farm infra sound; exclude |
| Sonus Pty Ltd | 2010 | Infrasound measurements from wind farms and other sources | | Background information on infrasound; exclude |
| Standing Senate Committee on Energy, The Environment and Natural Resources | 2011 | Industrial wind turbines and health: wind turbines can harm humans | The Society for Wind Vigilance | List of abstracts, no additional references to include; exclude |
| Standing Senate Committee on Energy, The Environment and Natural Resources | 2011 | Industrial wind turbines and health: wind turbines can harm humans | Presentation, 18 October 2011 | Background information on health effects of wind farm noise; exclude |
| Styles P, Stimpson I, Toon S, England R, Wright M | 2005 | Microseismic and infrasound monitoring of low-frequency noise and vibrations from windfarms: recommendations on the siting of windfarms in the vicinity of Eskdalemuir, Scotland | Keele University | Guidelines/regulations for wind farm siting; exclude |
| Suter AH | 1991 | Noise and its effects | Administrative Conference of the United States | Background information on noise and its impact; exclude |
| Swinbanks MA | 2012 | Infrasound from wind turbines | Letter from Malcolm Swinbanks | Commentary/opinion—letter; exclude |
| Swinbanks MA | 2011 | The audibility of low-frequency wind turbine noise | Fourth International Meeting on Wind Turbine Noise, Rome, Italy, 12–14 April 2011 | Background information on low-frequency noise; exclude |
| Swinbanks MA | 2012 | Numerical simulation of infrasound perception, with reference to prior reported laboratory effects | Inter-Noise Congress 2012, 19–22 August 2012, New York City | Background information on infrasound perception; exclude |
| Swinbanks MA | 2012 | Numerical simulation of infrasound perception, with reference to prior reported laboratory effects. | Power Point presentation at Inter-Noise Congress, 19–22 August 2012, New York City | Background information on infrasound perception; exclude |
| Swinbanks MA | 2012 | Numerical simulation of infrasound perception, with reference to prior reported laboratory | Paper presented to the First International Symposium on | Background information on infrasound perception; exclude |

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| | | effects | Adverse Health Effects from Wind Turbines, Picton, Ontario, 29–31 October 2010 | |
| Swinbanks MA | 2011 | Wind turbines: low-frequency noise, infrasound & health effects | Scottish National Wind Conference, Friday 11 November 2011, Prestwick, Scotland | Background information on wind turbine noise; exclude |
| Tamura H, Ohgami N, Yajima I, Iida M, Ohgami K, Fujii N, Itabe H, Kusudo T, Yamashita H, Kato M | 2012 | Chronic exposure to low-frequency noise at moderate levels causes impaired balance in mice | PLOS ONE: research article, published 29 June 2012; doi: 10.1371/journal.pone.0039807 | Study—unsuitable population; exclude |
| Tharpaland International Retreat Centre | 2003 | Effects of windfarms on meditative retreaters: a human impact assessment (Tharpaland International Retreat Centre) | | Commentary/opinion regarding visitors to an area proximal to a wind farm; exclude |
| Tharpaland International Retreat Centre | 2004 | An assessment of infrasound and other possible causes of the adverse effects of windfarms | | Background information on possible cause of health effects near wind farms; exclude |
| Tharpaland International Retreat Centre | | Executive summary: Three windfarm studies and an assessment of infrasound | Submission by Tharpaland International Retreat Centre (accompanied by additional documents) | Background information on health effects of wind farms; exclude |
| The Acoustic Group Pty Ltd | 2012 | Peer review of environmental noise assessment: Collector Wind Farm 42.5006.R1:ZSC | Prepared for Friends of Collector, C/- Hegarty and Elmgreen | Background information on noise effects, opinion paper; exclude |
| The Acoustic Group Pty Ltd | 2012 | Annexure A | Prepared for Friends of Collector, C/- Hegarty and Elmgreen | Background information on noise and wind farms; exclude |
| The Acoustic Group Pty Ltd | 2011 | Peer review of acoustic assessment: Flyers Creek Wind Farm 41.4963.R1A:ZSC | Prepared for Flyers Creek Wind Turbine Awareness Group Inc., 15 December 2011 | Background information on acoustic assessment; exclude |
| The Regional Municipality of Durham | 2010 | Correspondence advising of the resolution passed by the city of Oshawa: A. Endorsing the city of Pickering's motion requesting the region of Durham retain an integrity commissioner; B. Advising that the city of Oshawa will accept its share of the cost on per-use basis | | Commentary/opinion—letter; exclude |
| The Regional Municipality of Durham | 2010 | The potential health impact of wind turbines | Report No. 2010-MOH-18 | Narrative review; exclude |
| Thorne R | 2011 | The problem with 'noise numbers' for wind farm | *Bulletin of Science, Technology* | Narrative review; exclude |

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| | | noise assessment | *and Society* 2011; 31(4):262–290 | |
| Thorne R | 2010 | Hearing and personal response to sound | Rapley and Bakker (eds) 2010, pp. 69–78 | Background information only; exclude |
| Thorne R | 2010 | Health, wellbeing, annoyance and amenity | Rapley and Bakker (eds) 2010, pp. 93–101 | Background information only; exclude |
| Thorne R | 2010 | Synopsis of assessing intrusive noise and low-amplitude sound | Rapley and Bakker (eds) 2010, pp. 111–125 | Background information only; exclude |
| Thorne R | 2010 | Wind farms: the potential for annoyance | Rapley and Bakker (eds) 2010, pp. 127–133 | Background information only; exclude |
| Thorne R | 2010f | Noise from wind turbines | Rapley and Bakker (eds) 2010, pp. 217–224 | Background information only; exclude |
| Thorne R | 2011 | Wind farms in a rural environment and potential for serious harm to human health due to noise | Submission to the Senate Community Affairs Committee, 'Inquiry into the social and economic impacts of rural wind farms', 30 January 2011, rev.1 | Commentary/opinion paper; exclude |
| Thorne R, Rapley B, Heilig J | 2010 | Waubra Wind Farm Noise Impact Assessment for Mr & Mrs Dean; Report no. 1537, Rev. 1, July 2010 | | Background information on wind turbine noise assessment, particularly at the Waubra Wind Farm; exclude |
| Todd N | 2001 | Evidence for a behavioural significance of saccular acoustic sensitivity in humans | *Journal of the Acoustical Society of America* 2001; 110(1):380–390. | Background information only; exclude |
| Todd NP, Rosengren SM, Colebatch JG | 2008 | Tuning and sensitivity of the human vestibular system to low-frequency vibration | Faculty of Life Science, University of Manchester, UK; *Neuroscience Letters* 2008; 444(1):36–41 Epub 8 August 2008 | Background information only; exclude |
| Tognato C, Spoehr J | 2012 | *The energy to engage: wind farm development and community engagement in Australia* | Report prepared for the Institute for Mineral and Energy Resources, The University of Adelaide | Background information on community engagement and wind farms; exclude |
| Turnbull C, Turner J, Webb D | 2012 | Infrasound measurement results in Australia near wind turbines and other infrasound sources | Acoustics Australia (2012) Vol. 40, No. 1 | Background information—infrasound measurements, no health outcomes; exclude |
| UK Noise Association | 2006 | Location, location, location: an investigation into wind farms and noise | | Narrative review, personal testimonies; exclude |

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| University of Gothenburg | 2008 | *Wind farm perception: visual and acoustic impact of wind turbine farms on residents*; final report | FP6-2005-Science-and-Society-20; Specific Support Action, Project no. 044628 | Duplicate study/data—duplication of data from included study (van den Berg et al., see below); exclude |
| Van den Berg GP | 2005 | The beat is getting stronger: the effect of atmospheric stability on low-frequency modulated sound by wind turbines | *Journal of Low Frequency Noise, Vibration, and Active Control* 2005; 24(1):1–24 | Background information on wind turbine noise measurement; exclude |
| Van den Berg GP | 2003 | Effects of the wind profile at night on wind turbine sound | *Journal of Sound and Vibration* doi:10.1016/j.jsv.2003.09.050 | Background information on wind turbine noise measurement; exclude |
| Van den Berg GP | 2001 | Do wind turbines produce significant low-frequency sound levels? | Conference paper: 11th Meeting on Low Frequency Noise and Vibration and its Control, August 30 – September 1, Maastricht, Holland | Background information on wind turbine low-frequency noise; exclude |
| Van den Berg F, Pedersen E, Bouma J, Bakker R | | Visual and acoustic impact of wind turbine farms on residents | <https://www.wind-watch.org/documents/visual-and-acoustic-impact-of-wind-turbine-farms-on-residents/> | Study; **include** (provides additional information to the study by Bakker et al. (2012) identified in the black literature search) |
| Wang Z | 2011 | Evaluation of wind farm noise policies in South Australia: a case study of Waterloo Wind Farm | Case study | Study—does not include any comparative analysis, includes the same population as Morris's study (residents living near Waterloo Wind Farm); exclude |
| Watts CJ | 2011 | Submission to Department of Planning and Infrastructure on proposed Flyers Creek Wind Farm, Blayney local government area | Flyers Creek Wind Turbine Awareness Group Inc. | Commentary opinion—response to the proposal for wind farm at Flyers Creek, NSW; exclude |
| Watts CJ | 2011 | Flyers Creek submission: personal letters, 15 December 2011 | | Commentary/opinion—letters; exclude |
| Watts AC, Watts CJ | 2012 | Draft NSW Planning Guidelines Wind Farms submission, NSW Department of Planning and Infrastructure | | Background information on wind farm planning guidelines; exclude |
| Watts AC, Watts CJ | 2012 | Collector Wind Farm MP 10_0156; Proposed Collector Wind Farm, Upper Lachlan local government area (Ratch Australia Corporation): noise and health | | Background information on wind farm noise and effects, particularly the Waubra Wind Farm; exclude |
| Waubra Foundation | 2012 | Submission by Dr Sarah Laurie, CEO Waubra Foundation | | Commentary/opinion—letter; exclude |

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| Waubra Foundation | 2012 | Wind turbine acoustic pollution assessment requirements | | Commentary/opinion; exclude |
| Waubra Foundation | 2011 | Brief summary of field data collected from residents and visitors adversely impacted by infrasound and low-frequency noise (ILFN) emissions from a variety of sources in Australia | | Study—qualitative design; exclude |
| Waubra Foundation | 2012 | Collector Wind Farm development | Hon Brad Hazzard, Director General, NSW Department of Planning, individuals responsible for the decision re the Collector Wind Development | Not found by cut-off date; exclude |
| Wind Watch | | Wind energy facilitates local law, town of Litchfield, New York | | Commentary/opinion; exclude |
| Wolsink M, Sprengers M | 1993 | Wind turbine noise: a new environmental threat? | *Proceedings of the Sixth International Congress on the Biological Effects of Noise,* ICBEN, Nice, France, 1993; 2:235–238 | Background information only; exclude |
| Wolsink M, Sprengers M, Keuper A, Pedersen TH, Westra CA | 1993 | Annoyance from wind turbine noise on sixteen sites in three countries. | *Proceedings of the European Community Wind Energy Conference*, Lubeck, Travemunde, 1993; 273–276 | Not found by cut-off date; exclude |
| World Health Organization | 1990 | *Guidelines for community noise*, ed. by Berglund, B, Lindvall, T, Schwela, DH, World Health Organization, 1999 | | Guidelines/regulations for acceptable noise levels; exclude |
| World Health Organization | | *Constitution of the World Health Organization* | | Background only; exclude |
| World Health Organization | 2003 | WHO definition of health | | Background only; exclude |
| World Health Organization | 1998 | Health promotion glossary | | Background only; exclude |
| World Health Organization | 2008 | *Closing the gap in a generation: health equity through action on the social determinants of health* | | Background only; exclude |
| World Health Organization | 2009 | *Noise and health* | Copy of email correspondence | Background information on health effects of noise; exclude |
| World Health Organization | 2011 | *Occupational and community noise* | Fact sheet no. 258 | Background information on health effects of noise; exclude |
| World Health Organization | 2010 | *Mental health: strengthening our response* | Media centre fact sheet no. 220, | Background only; exclude |

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| World Health Organization Europe | 2009 | *Night Noise Guidelines for Europe*, World Health Organization, Copenhagen, 2009 | | Guidelines/regulations for acceptable noise levels; exclude |
| World Health Organization, Health and Welfare Canada | 1986 | *Ottawa Charter for Health Promotion* | | Background information only; exclude |
| World Health Organization, Regional office for Europe | 2012 | *Environmental health in equities in Europe* | | Background information only; exclude |
| World Health Organization, Regional office for Europe | 2004 | WHO LARES final report: *Noise effects and morbidity* | | Background information on health effects of noise; exclude |
| World Health Organization, Regional office for Europe | 2004 | WHO LARES final report: *Noise effects and morbidity* | Copy of website page | Background information on health effects of noise; exclude |
| World Health Organization, Regional office for Europe | 2007 | *Large analysis and review of European housing and health status (LARES)*: preliminary overview | | Background information only; exclude |
| Yang Y | 2009 | Gene and protein expression patterns in the rat inner ear during ototoxicity and otoprotection | Dissertation | Study—unsuitable population; exclude |