

**NHMRC Draft Information Paper:
Evidence on Wind Farms and Human Health**

Consultation draft — February 2014

CONSULTATION DRAFT

Contents

1	INTRODUCTION	2
1.1	Purpose of this document	2
1.2	Wind farms in Australia	2
1.3	Why NHMRC is conducting this work	2
2	OVERVIEW OF THE REVIEW PROCESS	3
2.1	The review	3
2.2	Oversight by the Reference Group	3
2.3	Quality assurance processes	3
3	SYSTEMATIC REVIEW METHODS AND RESULTS	4
3.1	Identification of the literature	4
3.2	Selection of the evidence	4
3.3	The included studies	6
3.4	Critical appraisal of the systematic review evidence	6
4	BACKGROUND REVIEW METHODS AND RESULTS	9
4.1	Identification of the literature	9
4.2	What was included	9
4.3	Critical appraisal of the background review evidence	9
5	DECIDING WHETHER WIND FARMS CAUSE HEALTH EFFECTS	10
6	EMISSIONS FROM WIND TURBINES	11
6.1	Noise	11
6.2	Shadow flicker	12
6.3	Electromagnetic radiation	12
7	FINDINGS OF THE REVIEW	13
7.1	Summary of the evidence	13
7.2	Noise	13
7.2.1	Systematic review evidence	13
7.2.2	Parallel and mechanistic evidence	15
7.2.3	Summary	16
7.3	Shadow flicker	16
7.3.1	Systematic review evidence	16
7.3.2	Background evidence	16
7.3.3	Summary	16
7.4	Electromagnetic radiation	17
7.4.1	Systematic review evidence	17
7.4.2	Background evidence	17
7.4.3	Summary	17
	APPENDICES	18
A	Membership and Terms of Reference of the Reference Group	18
B	Quality assurance measures	19
C	Areas for further research	20
	GLOSSARY	22
	REFERENCES	24

1 Introduction

1.1 Purpose of this document

This Information Paper provides Australians with a summary of the evidence on whether wind farms cause health effects in humans and explains how NHMRC developed its summary based on the findings of an independent evidence review.¹ It is intended for use by any person or group interested in wind farms.

This draft of the Information Paper is subject to revision in light of the submissions that are received during public consultation.

1.2 Wind farms in Australia

Wind turbines are towers with rotating blades that harness wind to produce electricity. A group of wind turbines is known as a wind farm and may be located on land or offshore.* Wind turbine design has evolved over the last 20 years to enable better exploitation of wind energy and to minimise noise.²⁻⁴

Wind farms have been promoted as a viable and sustainable alternative to traditional, non-renewable forms of energy production. Since the *Renewable Energy Act 2000* was legislated in Australia, the number of wind farms in Australia has grown substantially.⁵ In 2011 there were around 90 wind farms across the country, and more were being constructed or planned. The number of wind farms is expected to increase further in the next few years, as efforts to utilise renewable energy sources continue.

1.3 Why NHMRC is conducting this work

NHMRC is responsible for ensuring that Australians receive the best available, evidence-based and reliable advice on matters relating to improving health, and to preventing, diagnosing and treating disease. Some members of the community have reported that living near a wind farm has affected their health. Therefore NHMRC is investigating whether there is reliable evidence that exposure to specific emissions from wind farms — noise, shadow flicker and electromagnetic radiation — could cause health effects in humans.

The current investigation of the potential health effects of wind farms builds upon NHMRC's previous work in this area. In 2010, NHMRC's *Public statement: Wind turbines and health*⁶ was published, with supporting evidence *Wind turbines and health: A rapid review of the evidence*.⁷ The 2010 NHMRC Public Statement concluded that "[t]here is currently no published scientific evidence to positively link wind turbines with adverse health effects".⁶ Due to the limited amount of published scientific literature, NHMRC committed to carrying out a more extensive search for evidence.

This draft Information Paper provides an update to NHMRC's previous work in this area. It is based on a comprehensive review of the available scientific evidence, following well-established systematic review principles.

In Australia, responsibility for regulating the planning, development and operation of wind farms lies with the state, territory and local governments. The outcomes of NHMRC's review may assist these organisations to make decisions about the regulation of wind farms.

NHMRC's review of the evidence will enable well-designed and targeted research to be undertaken in the areas that have been identified as the gaps in the evidence base (see [Appendix C](#)).

* In this paper, wind turbines and wind farms are often used interchangeably.

2 Overview of the review process

2.1 The review

In examining whether wind farms cause health effects in humans, NHMRC commissioned Adelaide Health Technology Assessment (the reviewers) to conduct an independent review of the scientific evidence on the health effects of wind farms. To ensure that the independent review process was robust and transparent, internationally recognised methods were used to direct the identification, assessment and collation of the evidence.

The independent review involved:

- a systematic review of scientific evidence on health and health-related effects specifically related to distance from and exposure to any emissions from wind farms (direct evidence); and
- a background literature review to establish:
 - the likely level of exposure to emissions produced by wind farms at nearby residences;
 - whether it is plausible that noise, shadow flicker and electromagnetic radiation (of the type and at the levels produced by wind farms) might affect healthy functioning of the human body (mechanistic evidence); and
 - whether any health and health-related effects have been observed from these emissions when they are produced by sources other than wind farms (parallel evidence).

2.2 Oversight by the Reference Group

The development of the literature review was guided by the Wind Farms and Human Health Reference Group (Reference Group). Information on the membership and Terms of Reference of the Reference Group is included at [Appendix A](#).

The Reference Group has expertise in public and environmental health, research methodology, acoustics, psychology and sleep, and includes a consumer representative. Its role included:

- assisting the reviewers to develop research questions;
- reviewing and commenting on drafts of the review report;
- providing scientific advice on the interpretation of the evidence;
- guiding the development of the draft Information Paper; and
- identifying gaps in the evidence base to make recommendations for further research ([Appendix C](#)).

2.3 Quality assurance processes

Rigorous quality assurance processes support the development of all NHMRC health advice. The processes used to ensure the quality of the independent review and the draft Information Paper are outlined in [Appendix B](#).

3 Systematic review methods and results

3.1 Identification of the literature

The systematic component of the independent review searched for all of the scientific evidence on health and health-related effects specifically related to exposure to any emissions from wind farms. This is referred to as the *direct* evidence.

The reviewers undertook a comprehensive search of the literature in accordance with a pre-approved review protocol and search strategy for the independent review. The search strategy was kept broad to make sure that no study was missed. Literature for possible inclusion in the systematic review was identified by:

- searching publication databases for peer-reviewed health literature;
- searching for relevant non peer-reviewed literature (commonly referred to as grey literature) in Google Scholar, databases of conference proceedings, selected government and scientific association websites, and other grey literature sources; and
- checking the reference lists of relevant reviews and reports.

NHMRC also called for public submissions of relevant literature for inclusion in the systematic component of the independent review in September 2012, to help ensure that all new and emerging evidence was considered.

The reviewers identified 2850 references, and an additional 506 references were received by NHMRC during the call for public submissions. The review encompassed all evidence published after the first commercial wind farm was established in 1981, up until October 2012 (the time that the search strategy was agreed and the search was undertaken).

3.2 Selection of the evidence

For information to be considered in the systematic component of the independent review, it had to:

- be publicly available;
- look at exposure to wind farm emissions;
- *not* choose participants only because they had reported health effects;
- compare two or more groups with different levels of exposure to wind turbines (e.g. a “near” group and a “far” group);
- explain how the data were collected;
- report on health (or health-related) outcomes; and
- analyse the results.

Personal stories, opinions and medical records submitted by individuals were not considered in the independent review.

Titles and abstracts of all 2850 identified papers and the additional 506 submitted references were reviewed for relevance. 161 papers were then read in detail. Only seven studies (described in eleven papers) met the inclusion criteria listed above (see Figure 1).

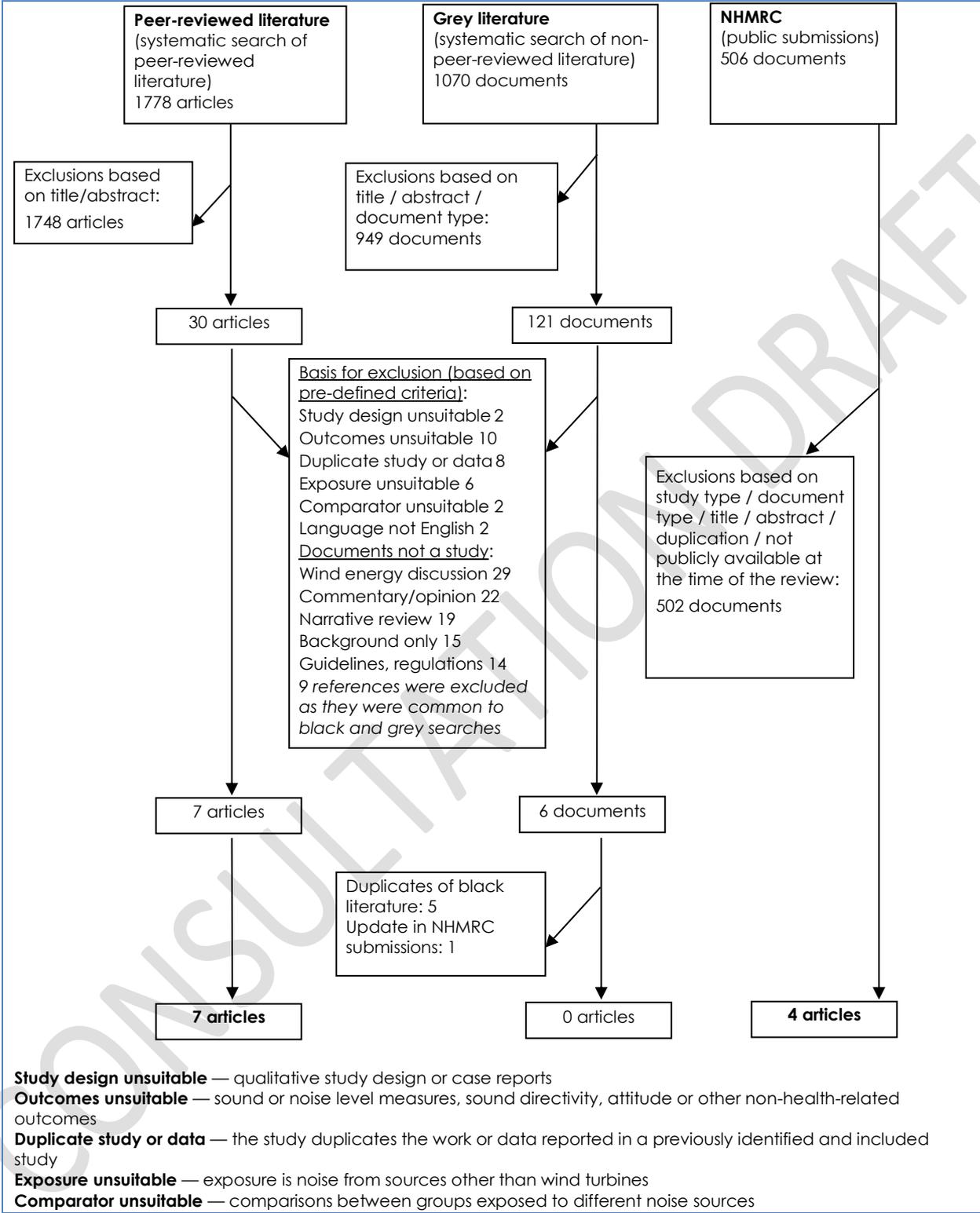


Figure 1: Process of selecting literature for inclusion

Source: Adapted from the report of the independent review,¹ Figure 1, page 44.

3.3 The included studies

The seven studies included in the independent review examined wind farm noise or shadow flicker and changes to one or a combination of physical health, mental health and health-related outcomes.

- Five studies assessed self-reported **physical health outcomes** and estimated level of wind farm noise⁸⁻¹⁰ or proximity to wind farms.^{11,12}
- Five studies assessed aspects of self-reported **mental health** (stress, irritability, psychological distress, anxiety and depression) and estimated level of wind farm noise⁸⁻¹⁰ or proximity to a wind farm.^{12,13}
- Five studies assessed **annoyance** and estimated level of wind farm noise^{8,9,14} or proximity to a wind farm.^{11,15} The one Australian study also assessed annoyance and shadow flicker from wind turbines.¹⁵
- All seven studies assessed self-reported **sleep quality** and estimated level of wind farm noise⁸⁻¹⁰ or proximity to a wind farm.^{11-13,15}
- Three studies assessed **quality of life** and proximity to wind farms.¹¹⁻¹³

Of the seven studies, only one was conducted in Australia. The remaining studies were conducted in the Netherlands, Canada, the United States of America and Sweden.

In all these studies, the participants **self-reported** their health and health-related outcomes; none of the outcomes were objectively measured (e.g. by using a test performed by a doctor or scientist).

No studies were identified that specifically looked at possible effects on human health of **infrasound** (sound at a frequency lower than 20 Hertz) and **low-frequency noise** or **electromagnetic radiation** from wind turbines.

3.4 Critical appraisal of the systematic review evidence

Some studies provide stronger evidence than others because of their size and the way they are designed and conducted. In addition, the evidence for a particular relationship is stronger if there are multiple 'well done' studies that are consistent in their findings.

The reviewers assessed the design, quality, relevance and strength of each study included in the independent review. The overall body of evidence was then analysed for its quality and consistency. The key features of the studies were summarised in a table in the report of the independent review¹ (see Table 7, page 47) and an overview is provided below.

Study design and sample sizes

All seven studies that met the inclusion criteria for the systematic component of the independent review used a cross-sectional design. Cross-sectional studies examine the relationship between an exposure (in this case wind turbines) and specific health outcomes in a defined population at a single point in time. Because the health outcomes were assessed at a single point in time, none of the included studies were able to provide any indication of the order of events — that is, whether a health outcome first occurred before or after the exposure began. This might mean that a person's self-reported health outcomes were present *prior* to the person's exposure to wind turbines.

The number of participants in most of the studies was modest. Larger numbers provide greater certainty as to whether any observed association between an exposure and an outcome can be explained by chance. Larger numbers are particularly important if an exposure is likely to have only a small effect on the outcome, and when an exposure or health outcome is rare in the study population.

Selection bias

In scientific studies, the term *bias* is used to describe the effect of an error in the design of a study or an error or problem in the collection, analysis, reporting, publication or review of study data that leads to untrue results.

All studies included in the systematic component of the independent review had low participation rates, meaning that many people who were approached to be part of the study did not participate. There is a high risk of selection bias in a study with a low participation rate, as those who chose to participate in the study may have different exposure and health outcomes to those who did not participate. For example, people who are unwell may be more willing to take part if they live close to wind farms than if they do not live close to wind farms.

In many of the studies, the purpose of the research was not masked (i.e. hidden) from participants. Where the studies did attempt to hide the intent of the study from participants, this may not have been effective. A lack of successful masking of a study's purpose can contribute to selection bias by making it more likely that a person who is concerned about wind farms will take part than a person who is not concerned about wind farms.

Information bias

All of the health and health-related outcomes recorded in the included studies were self-reported. It is known that people often have difficulty in accurately recalling their health details and the timing of onset of their symptoms.^{16,17} If this inaccuracy is not random, a false association may be observed. For example, knowledge of a wind farm study's purpose may make people living near a wind farm try harder to recall their health details than people who live further away. This could make people who live further away from the wind farm appear less sick than those living closer, when there is actually no difference.

Confounding factors

When there seems to be an association between an exposure and an outcome, it is important to consider whether this might be due to another factor that is associated with both the exposure and the outcome — this is known as a *confounding factor*. For example most common physical health conditions (e.g. high blood pressure, diabetes, heart disease) are more common in older than younger people. If people in a study who lived nearer to wind farms were, on average, older than people who lived further away, physical health conditions would be more common in those living close to the wind farm. This might only be due to the age difference and nothing to do with wind farms. In this example, age is a confounding factor.

The systematic review identified a number of confounding factors that might influence the association between wind farms and health or health-related outcomes (such as socioeconomic status, pre-existing chronic diseases, and attitude to, visibility of or economic benefit from wind farms). These factors were not consistently measured in the available studies and when they were, their possible effects on associations between wind farms and health or health-related outcomes were not always taken into account when analysing the results.

Consistency

It is rarely possible to be confident that there is a cause-and-effect relationship based on one study because the results may be affected by chance, selection or information bias, or confounding. However if an observed association in one study is consistently found in other studies (that ideally have been conducted in different ways and by different investigators), this consistency strengthens the case for a cause-and-effect relationship. Similarly when study results are not consistent, it is more likely that the association is due to chance, selection or information bias, or confounding; that is, the association does not indicate a cause-and-effect relationship.

Among the seven studies reviewed, there was no consistency in finding an association between wind turbine exposure and self-reported physical or mental health outcomes. However there was some consistency in showing associations between wind farm exposure and annoyance, disturbed sleep and poorer quality of life.

Overall quality rating

Considering all the issues discussed above, the Reference Group graded the direct evidence on the relationship between health and health-related effects and wind turbine noise and shadow flicker as **Grade D** (the body of evidence is weak and cannot be trusted), following NHMRC criteria for assessing the quality of evidence.¹⁸ This grading is largely due to the methodological weakness of the cross-sectional design used by all studies. It was also strongly influenced by the high risk of selection or information bias in most of the studies, and the lack of adequate measurement or control of potentially confounding factors.

Table 1: Description of evidence statement grades

Grade	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

Source: Adapted from the NHMRC FORM system.^{19,20}

4 Background review methods and results

4.1 Identification of the literature

In addition to the systematic component of the independent review, a broad background literature search was conducted to describe the circumstances under which wind farms operate and how they may affect human health.

The background component of the independent review included general literature on wind turbines and wind farms, the emissions that they produce, and the likely level of exposure to those emissions among people living nearby. The purpose of this component of the independent review was to provide a general background understanding of these issues. Due to the breadth of the topics covered, the reviewers did not systematically search and select studies. Instead, the reviewers looked for key publications in the peer-reviewed literature, particularly those providing up-to-date reviews of relevant evidence, as well as technical reports and analyses prepared by expert panels and environmental health agencies.

The background component of the independent review also sought to establish whether it is plausible that noise, shadow flicker and electromagnetic radiation might affect healthy functioning of the human body (mechanistic evidence). In addition, it examined whether any health or health-related effects have been observed from these emissions when produced by sources other than wind farms (parallel evidence). These aspects of the background review followed a more structured approach, by searching publication databases for peer-reviewed health literature using pre-specified key words and search terms.

Reference Group members also brought forward additional published background evidence not included in the reviewers' background review, based on their knowledge and expertise in the relevant subject matters (including public and environmental health, research methodology, acoustics, sleep and psychology).

4.2 What was included

Background evidence identified through this component of the independent review included World Health Organization reports on health effects associated with environmental noise²¹ and on electromagnetic radiation emissions from household appliances and the environment,^{22,23} a United States report on the impact of wind farms,² and South Australian data on infrasound levels near wind farms and other environments.²⁴ Laboratory studies on changes in functioning of the human body due to exposure to infrasound or low-frequency noise²⁵⁻²⁷ and epidemiological studies on exposure to electromagnetic radiation²⁸ were also reviewed.

4.3 Critical appraisal of the background review evidence

Given the exploratory nature of the background component of the independent review, no formal quality appraisal of these studies was conducted. However in formulating the overall conclusions and developing this draft Information Paper, the Reference Group carefully considered the value and strength of the evidence provided by each relevant background study.

5 Deciding whether wind farms cause health effects

Studies investigating whether living near wind farms might have adverse health effects (direct evidence) can only establish whether there is an *association* between living near wind farms and experiencing a particular health outcome. Generally, an association is 'established' if it has been directly observed in several different studies and is judged unlikely to simply be a chance finding. Deciding whether an association between wind farm exposure and a particular health outcome is causal — that is, wind farm exposure *causes* the health outcome — requires more evidence.

- First, it must be clear that the exposure (to wind turbines) preceded the outcome (the health or health-related effect).
- Second, it must be possible to rule out alternative explanations for the association, including both:
 - bias resulting from the design of the study or the way the study was conducted; and
 - causation by one or more confounding factors associated with wind farm exposure.
- Third, it should be shown:
 - that the association is consistent with other evidence on the effects of the exposure (e.g. noise from some other source); and
 - ideally, that there is a biological mechanism by which the exposure could cause the health outcome with which it is associated.

NHMRC found no consistent direct evidence that exposure to wind farms was associated with any health outcome. The few associations reported by individual studies could have been due to chance. Therefore NHMRC concluded there is no reliable or consistent evidence that wind farms directly cause adverse health effects in humans.

NHMRC found consistent direct evidence that proximity to wind farms was associated with annoyance and less consistently, with sleep disturbance and poorer quality of life. The poor quality of the studies from which this evidence came, however, meant that selection and information bias and confounding were possible explanations for the associations observed. Therefore even though there was support for some of these associations in studies of effects of noise from other sources, NHMRC could not conclude that exposure to wind farm noise *causes* annoyance, sleep disturbance or poorer quality of life.

6 Emissions from wind turbines

6.1 Noise

Sound travels from a source as a wave (pressure variation) through a medium (e.g. air, water) to a receiver (e.g. the human ear). The number of complete waves passing a given point in one second is the frequency of the wave, expressed in terms of the number of cycles (waves) per second. The unit of frequency is the Hertz: one Hertz is one cycle per second. People sense the frequency of a sound by what is thought of as its pitch — e.g. high pitch is used to describe a high frequency sound and low pitch is used to describe a low-frequency sound. What is sensed as pitch, however, is affected by the level (“loudness”) of the sound as well as its frequency.

Sounds in the frequency range 20–20000 Hertz can normally be heard by humans (the upper limit decreases with age).²⁹ Sound at a frequency lower than 20 Hertz is generally termed ‘infrasound’. Human hearing becomes gradually less sensitive as frequency decreases, so a low-frequency sound (lower than 100 Hertz) needs to be at a higher level (“louder”) to be heard than a mid-range frequency (e.g. 1000 Hertz). High frequency sound reduces in level (becomes quieter) more quickly with increase in distance than low-frequency sound and is attenuated more by doors and windows (i.e. does not pass through as easily). Lower frequency sounds can travel further through most media than higher frequency sounds.³⁰

Sound level is measured in a unit called a decibel (dB). Because the ability of humans to hear sound varies with frequency, measurements of noise often take this variation into account by giving more weight to frequencies that are more easily heard and less weight to frequencies it is harder to hear at the sound levels at which these frequencies normally occur. This process is called A-weighting and the sounds measured in this way are expressed in terms of dBA. For example the background noise level in an open plan office is usually about 40–45 dBA.

When a sound or a combination of sounds is unwanted it is considered “noise”. The human perception of sound is only partly related to the acoustic stimulus, that is, to the mix of frequencies in the sound, its level and its other physical characteristics (e.g. variation over time or tonality”). Many other factors are important in determining the perception and reaction to a given sound. These include a person’s physical health and psychological state, their attitude towards the perceived source of the sound, their perceived control of the sound, individual variation in how the brain processes sounds when awake and during sleep, and timing (e.g. sounds considered acceptable during the day may be perceived as noise during the night if sleep is disturbed).³² In NHMRC’s review of wind farms and human health, all sound from wind turbines is referred to as “noise”.

* Noise containing a prominent frequency and characterised by a definite pitch.³¹

Wind turbines produce mechanical sound at a frequency of 20–30 Hertz (for a 1500 kilowatt turbine)² and a “whooshing” aerodynamic sound in the range of 200–1000 Hertz.^{33,34} Noise from wind farms is mostly aerodynamic.^{8,9,35}

It is difficult to estimate the level of noise from wind farms in the presence of background noise. As the sound level decreases with distance, it is unlikely that substantial noise would be heard at distances of more than 500–1500 m from wind farms.^{2,36} Noise levels vary with terrain, type of turbine and weather conditions.

Infrasound is considered by some to be an important component of the noise from wind farms. Evidence suggests that levels of infrasound are no higher in environments near wind turbines than in a range of other environments. For example, a South Australian study observed similar levels of infrasound at rural locations close to wind turbines, rural locations away from wind turbines, and at a number of urban locations.²⁴

6.2 Shadow flicker

Shadow flicker, as it relates to wind turbines, is defined as the flickering effect caused when rotating wind turbine blades intermittently cast moving shadows on the ground, resulting in alternating changes in light intensity.

Exposure to flicker from a turbine depends on the wind turbine's hub height and blade diameter, the wind direction and geographical location, and the direction and height of the sun (affected by the time of day and time of year).^{37,38} Shadow flicker is generally present only at distances of less than 1.4 km from wind turbines.²

6.3 Electromagnetic radiation

Electromagnetic radiation broadly refers to combinations of electric and magnetic waves. Electromagnetic radiation is emitted by a range of common domestic appliances (e.g. vacuum cleaners, microwave ovens, colour televisions and mobile phones).

Extremely low-frequency electromagnetic radiation is the only potentially important electromagnetic emission from wind turbines.³⁹ The very limited information available suggests that the level of extremely low-frequency electromagnetic radiation close to wind farms is less than that found one metre from common household appliances when in use and much less than the average level measured inside and outside Australian suburban homes.²²

7 Findings of the review

7.1 Summary of the evidence

Statement on the evidence

There is no reliable or consistent evidence that wind farms directly cause adverse health effects in humans.

Noise

- There is no reliable or consistent evidence that proximity to wind farms or wind farm noise directly causes health effects.
- There is consistent but poor quality evidence that proximity to wind farms is associated with annoyance and, less consistently, with sleep disturbance and poorer quality of life. Finding an association between wind farms and these health-related effects does not mean that wind farms cause these effects. These associations could be due to selection or information bias or to confounding factors.
- There is no direct evidence that specifically considered possible health effects of infrasound or low-frequency noise from wind turbines.
- It is unlikely that substantial wind farm noise would be heard at distances of more than 500–1500 m from wind farms. Noise levels vary with terrain, type of turbines and weather conditions.
- Noise from wind turbines, including its content of low-frequency noise and infrasound, is similar to noise from many other natural and human-made sources. There is no evidence that health or health-related effects from wind turbine noise would be any different to those from other noise sources at similar levels.
- People exposed to infrasound and low-frequency noise in a laboratory (at much higher levels than those to which people living near wind farms are exposed) experience few, if any, effects on body functioning.

Shadow flicker

- There is insufficient direct evidence to draw any conclusions on an association between shadow flicker produced by wind turbines and health outcomes.
- Flashing lights can trigger seizures among people with a rare form of epilepsy called photosensitive epilepsy. The risk of shadow flicker from wind turbines triggering a seizure among people with this condition is estimated to be very low.

Electromagnetic radiation

- There is no direct evidence on whether there is an association between electromagnetic radiation produced by wind farms and health outcomes.
- Extremely low-frequency electromagnetic radiation is the only potentially important electromagnetic emission from wind turbines.
- Limited evidence suggests that the level of extremely low-frequency electromagnetic radiation close to wind farms is less than average levels measured inside and outside Australian suburban homes.
- There is no consistent evidence of human health effects from exposure to extremely low-frequency electromagnetic radiation at much higher levels than is present near wind farms.

7.2 Noise

7.2.1 Systematic review evidence

In the studies included in the systematic component of the independent review, wind turbine noise was not directly measured at participants' homes. Rather people's exposure to wind farm noise was assessed based on how far they lived from the nearest wind turbine (proximity) or by using mathematical models to estimate the level of sound where they lived. The mathematical models take into account a range of factors including sound output from the turbines and distance to the house.

Even where consistent associations were found between estimated wind turbine noise and health-related outcomes (such as annoyance), it was not possible to tell whether the noise was driving the association, or whether the association could be explained by one or more other factors that are more common among people living close to wind farms (such as attitude to, visibility of or economic benefit from wind farms).

All studies identified in the systematic review were considered to be poor quality (see section 3.4).

Health outcomes

Health outcomes are changes in the health status of an individual or group. These can be measured (e.g. through biological tests) or self-reported (e.g. in a questionnaire). The health outcomes reported in the studies in the systematic component of the independent review were all self-reported by participants.

Physical health

Five studies assessed self-reported physical health outcomes and estimated level of wind farm noise⁸⁻¹⁰ or proximity to wind farms.^{11,12} Collectively these studies reported on chronic diseases, cardiovascular disease, ratings of general health, blood pressure, headaches, tinnitus, hearing loss and whether participants had sought help from a doctor.

The results of one study suggested a link between estimated wind farm noise and tinnitus⁹ and another study suggested a link between wind farm noise and increased prevalence of diabetes.⁸ However other studies that looked at tinnitus^{8,10,12,40} or diabetes^{10,40} did not find a significant association. No links were found between estimated wind farm noise or distance from wind farms and any of the other physical health outcomes.⁸⁻¹²

Mental health

Five studies assessed aspects of self-reported mental health (stress, irritability, psychological distress, anxiety and depression) and estimated level of wind farm noise⁸⁻¹⁰ or proximity to a wind farm.^{12,13} Four studies found no significant differences in the mental health of participants.^{8-10,12} Three of those masked the purpose of the study.⁸⁻¹⁰ One study reported that individuals who lived closer to wind farms had lower mental health scores in a self-completed health questionnaire, however in that study the purpose of the study (being to investigate the health effects of wind farms) was explained to participants.¹³ In studies where the purpose was known, it is possible that people affected by wind farms were more likely to take part than people who are not affected. Knowing the study's purpose also may have made people living near a wind farm try harder to recall their health details than people who live further away.

Health-related outcomes

Health-related outcomes are not themselves health outcomes but may be indicators of health status or may affect health if they persist. For example, having a few nights of disturbed sleep does not mean a person is ill, but the stress resulting from repeated sleep disturbance may lead to ill health.³² Similarly poorer quality of life scores may indicate underlying mental or physical health issues. The health-related outcomes considered in the included studies were annoyance, poor or disturbed sleep and poorer quality of life.

Annoyance

Five studies assessed the association of annoyance with exposure to estimated wind farm noise^{8,9,14} or proximity to a wind farm.^{11,15} Although annoyance is not considered a health outcome by itself (i.e. it is a negative response and does not necessarily reflect health status), it may result in stress, which over the longer term may influence physical and mental health.³²

The five studies all reported an association between annoyance and higher estimated levels of wind farm noise^{8,9,14} or living closer to a wind farm.^{11,15} Rates of annoyance differed greatly between studies depending on the estimated noise exposure, definition of annoyance and whether the purpose of the study was masked from participants.

Factors other than the noise produced by wind farms, such as the participants' demographic, psychological and biological factors, their attitudes and perceived degree of control, and situational factors (including day and time, activity disturbance, type of area and features of the dwelling) may have contributed to the annoyance reported by participants.⁴¹

Sleep

The association of wind farm noise with self-reported sleep quality was assessed in all seven studies. Six studies reported poorer sleep (mostly disturbed sleep and poor sleep quality) among people exposed to higher estimated levels of wind farm noise⁸⁻¹⁰ or living closer to wind farms.^{11,12,15} Only one study asked participants whether they slept better when they were away from wind farms; most participants in that study said they did sleep better.¹³ The studies did not assess whether poorer sleep associated with wind farm noise might have had any effect on health.

The reported associations of wind turbine noise with sleep quality were generally weak. In some of the studies, the association between estimated wind farm noise and sleep quality was weaker than the association between wind farm noise *annoyance* and sleep quality.^{8,9}

Only some of the studies considered possible confounding factors in their analysis. In one study that did consider possible confounding factors, participants who did *not* economically benefit from wind turbines reported more sleep interruption than others.¹⁰ This was reported regardless of how close they were to the wind farm. Therefore it is possible that factors other than noise (such as economic benefit) could explain the apparent association between wind turbine proximity and sleep disruption.

Quality of life

'Quality of life' refers to a person's view 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. Quality of life may be affected by physical health, psychological state, level of independence and social relationships, and by features of the environment.⁴² Therefore poor quality of life may be an indicator of poor health.

Three studies assessed quality of life and proximity to wind farms.¹¹⁻¹³ Only one of them attempted to mask the purpose of the study from participants and used a formally validated questionnaire.¹¹ This study found an association between distance from wind turbines and overall quality of life. Two other studies used author-formulated questions and did not mask the purpose of the study. In one of these studies, the majority of people reported that their quality of life had altered since living near a wind turbine, regardless of how close they lived to the turbine.¹³ The other study reported that more residents living close to a turbine wanted to move away than residents living further from a turbine.¹²

However the studies did not explore whether these associations could be explained by other factors (e.g. annoyance at the wind farm, visibility of the wind farm or economic benefit from the wind farm).

7.2.2 Parallel and mechanistic evidence

Noise in other environments

High levels of noise from sources other than wind farms have been consistently associated with hearing loss, disturbed sleep and annoyance.^{21,32} Associations between noise exposure and some other health conditions (including high blood pressure, heart attack and depression) have also been suggested, but these associations are based on limited evidence.¹⁹ Most of the studies into the health effects of noise have been about exposure to noise from road traffic, aircraft or rail,² and generally examine exposure to noise at levels of the order of, or higher than, expected from wind turbines at 500 m.

The World Health Organization reported a number of effects on sleep when night noise is in the range of 30–40 dBA (measured outside).⁴³ These include body movements, awakening, self-reported sleep disturbance and arousals. The intensity of the effect varies with the nature of the source of the noise and the number of noise events. Vulnerable groups (e.g. children, people who are chronically ill and elderly people) are more susceptible to effects on sleep. However even in the worst cases, the effects are modest.

There is no evidence that health or health-related effects from wind turbine noise would be any different to those from other noise sources at similar levels. Based on the studies referred to above, wind turbines would be unlikely to cause any direct health effects at distances of more than 500 m. At 500-1500 m from a wind farm, wind turbine noise levels are generally in the range 30–45 dBA.³⁶ At these distances, effects on sleep are likely to be modest, if any. At distances of more than 1500 m from wind turbines, where noise levels are generally less than 30 dBA, sleep disturbance is unlikely.

The noise in the studies discussed above would have included infrasound, which is considered by some to be an important component of the noise from wind farms. The infrasound from these other noise sources would be at similar levels to that from wind turbines.²⁴ Therefore the evidence summarised above applies as much to infrasound as it does other sound frequencies from wind farms.

Laboratory studies

Laboratory studies have investigated changes in healthy functioning of the human body when people are exposed to infrasound or low-frequency noise. The studies suggest that high level low-frequency noise and infrasound leads to small and inconsistent changes in blood pressure, pulse or heart rate.²⁵ High levels of low-frequency noise may also cause temporary hearing loss.^{26,27}

7.2.3 Summary

- There is no reliable or consistent evidence that proximity to wind farms or wind farm noise directly causes health effects.
- There is consistent but poor quality evidence that proximity to wind farms is associated with annoyance and, less consistently, with sleep disturbance and poorer quality of life. Finding an association between wind farms and these health-related effects does not mean that wind farms cause these effects. These associations could be due to selection or information bias or to confounding factors.
- There is no direct evidence that specifically considered possible health effects of infrasound or low-frequency noise from wind turbines.
- It is unlikely that substantial wind farm noise would be heard at distances of more than 500–1500 m from wind farms. Noise levels vary with terrain, type of turbines and weather conditions.
- Noise from wind turbines, including its content of low-frequency noise and infrasound, is similar to noise from many other natural and human-made sources. There is no evidence that health or health-related effects from wind turbine noise would be any different to those from other noise sources at similar levels.
- People exposed to infrasound and low-frequency noise in a laboratory (at much higher levels than those to which people living near wind farms are exposed) experience few, if any, effects on body functioning.

7.3 Shadow flicker

7.3.1 Systematic review evidence

No studies were identified that assessed the health effects of shadow flicker from wind turbines.

One small study with a high risk of selection and information bias reported that people who lived within 5 km of a wind farm were more likely to notice and be annoyed by shadow flicker than those who lived 5–10 km away.¹⁵

7.3.2 Background evidence

It is known that flashing lights can trigger seizures among people with a rare form of epilepsy called photosensitive epilepsy. The risk of shadow flicker from wind turbines causing an epileptic seizure is estimated to be less than 1 in 10 million in the general population⁴⁴ and 17 in 1 million among people at risk of photosensitive epilepsy.³⁷

There is no evidence that investigates whether a laboratory 'equivalent' of wind turbine shadow flicker is associated with any physiological response or health effect.

7.3.3 Summary

- There is insufficient direct evidence to draw any conclusions on an association between shadow flicker produced by wind turbines and health outcomes.
- Flashing lights can trigger seizures among people with a rare form of epilepsy called photosensitive epilepsy. The risk of shadow flicker from wind turbines triggering a seizure among people with this condition is estimated to be very low.

7.4 Electromagnetic radiation

7.4.1 Systematic review evidence

No studies were identified that specifically assessed the health effects of electromagnetic radiation from wind turbines.

7.4.2 Background evidence

Concerns regarding the safety of exposure to electromagnetic radiation were raised with the publication of a study reporting a link between childhood leukaemia and extremely low-frequency electromagnetic radiation exposure from electricity transmission lines.²⁸ Subsequent research has looked for possible links between occupational exposure to extremely low-frequency electromagnetic radiation and cancer and cardiovascular, neurological, psychological or reproductive conditions in adults. The results of these studies have been inconsistent and no conclusions can be drawn about a cause-and-effect relationship between extremely low-frequency electromagnetic radiation exposure and human health effects.⁴⁵

Exposure to extremely low-frequency electromagnetic radiation can induce electrical currents in human tissue; the significance of these currents to human health is not known.²³

7.4.3 Summary

- There is no direct evidence on whether there is an association between electromagnetic radiation produced by wind farms and health outcomes.
- Extremely low-frequency electromagnetic radiation is the only potentially important electromagnetic emission from wind turbines.
- Limited evidence suggests that the level of extremely low-frequency electromagnetic radiation close to wind farms is less than average levels measured inside and outside Australian suburban homes.
- There is no consistent evidence of human health effects from exposure to extremely low-frequency electromagnetic radiation at much higher levels than is present near wind farms.

Appendices

A Membership and Terms of Reference of the Reference Group

Membership

Members	
Professor Bruce Armstrong (Chair)	Honorary Professor School of Public Health The University of Sydney
Professor Michael Abramson	Professor of Clinical Epidemiology Epidemiology & Preventive Medicine School of Public Health & Preventive Medicine Monash University
Professor Ronald Grunstein	Professor of Sleep Medicine Woolcock Institute of Medical Research, Central Clinical School, The University of Sydney and Royal Prince Alfred Hospital
Professor Debra Rickwood	Professor of Psychology Faculty of Health, University of Canberra Head, Clinical Leadership and Research Headspace National Youth Mental Health Foundation
Professor Wayne Smith	Director, Environmental Health Branch, NSW Health Conjoint Professor of Epidemiology, University of Newcastle Honorary Professor of Public Health, University of Sydney
Dr Norm Broner	Practice Leader – Acoustics, Noise and Vibration Sinclair Knight Merz
Dr Elizabeth Hanna	Fellow, National Centre for Epidemiology & Population Health ANU College of Medicine, Biology and Environment
Anne McKenzie	Consumer Advocate The University of Western Australia's School of Population Health and the Telethon Institute for Child Health Research
Observers	
Peter Mitchell	Honorary Chairman, Waubra Foundation Member of Board of Governors, Florey Neuroscience Institute Patron, Children First Foundation
Russell Marsh	Policy Director, Clean Energy Council

Terms of Reference

1. The Wind Farms and Human Health Reference Group will guide the development of a systematic review to determine if new evidence exists in the peer reviewed scientific literature on possible health effects of wind farms, by providing advice to the Office of NHMRC on the:
 - a. scope and questions the systematic review will address;
 - b. methods to identify relevant published guidelines and systematic review; and
 - c. methods to evaluate relevant published guidelines and systematic reviews.
2. The Wind Farms and Human Health Reference Group will consider the outcomes of the review and use these finding to:
 - a. inform updating NHMRC's Public Statement: Wind Turbines and Human Health; and
 - b. identify critical gaps in the current evidence base.
3. The Wind Farms and Human Health Reference group will provide NHMRC's Prevention and Community Health Care Committee with a report on Wind Farms and Human Health which is to include advice on the systematic review outcomes, updating the Public Statement and, possible need for further research, for consideration before recommendation to Council.

B Quality assurance measures

Rigorous quality assurance processes support the development of all NHMRC health advice. The quality assurance processes used to support the quality of the independent evidence review and the draft Information Paper are outlined below.

- *Reference Group observers* — Two observers were appointed to the Reference Group to observe the robust and transparent process. The observers do not have any influence over the discussions or decision-making processes of the Reference Group.
- *Reference Group declaration of interests* — As part of their formal appointment to the Reference Group, each member and observer was required to disclose any factors that may cause or be perceived to cause a conflict of interest with their duties as members of the Reference Group. The declared interests of all Reference Group members and observers have been published on NHMRC's website. The Reference Group Chair reviewed each member's declared interests and no unmanageable conflicts were identified.
- *Methodological review* — Independent reviewers from the National Collaborating Centre for Environmental Health (NCCEH) in Canada examined the methodological quality of the systematic review report, to ensure that the review followed the systematic and rigorous approach documented in the review protocol. The reviewers from NCCEH were appropriately qualified in systematic review processes and have previous experience in reviewing the scientific evidence on possible health effects of wind farms. The methodological review team completed a declaration of interest process before being appointed by NHMRC and no conflicts of interest were identified. The independent reviewers assessed the methodological quality of the systematic review as high.
- *Public consultation* — The draft Information Paper has been released for public consultation, accompanied by the supporting systematic review report. The public consultation process allows members of the public to make submissions about the document, comment on the evidence-based approach that was undertaken and provide any relevant evidence published after October 2012. The draft Information Paper may be revised in light of the submissions that are received during public consultation.
- *Expert review* — In parallel with public consultation, the Information Paper is undergoing expert review to ensure that the evidence has been appropriately interpreted and synthesised. Expert reviewers have been asked to consider a number of factors, including:
 - the comprehensiveness of the literature reviewed;
 - the validity of conclusions drawn from the evidence and any alternative conclusions that could be drawn; and
 - whether the limitations of the review have been adequately explained and addressed.

NHMRC has selected a number of international and Australian experts in the fields of acoustics, psychology, sleep and epidemiology to conduct the expert review. Before being appointed, potential expert reviewers were required to declare any interests that may be perceived to cause a conflict with their role as an expert reviewer. Following the expert review process, the names and declared interests of the expert reviewers will be published on NHMRC's website.

C Areas for further research

Further evidence is needed to explore the relationships between noise at varying distances from wind farms and other health-related effects such as annoyance, sleep and quality of life. Research is also required to investigate the broader social and environmental circumstances that influence self-reported health effects and health-related effects in people living near wind farms.

Gathering sufficient quality evidence in these two areas may assist governments and planning authorities to make evidence-based decisions regarding wind farm policy, planning and development. Community engagement and participation would be beneficial in ensuring that research is appropriately targeted to the community's areas of concern.

The Reference Group has identified a number of themes for further research. It is important that research measuring and characterising wind turbine noise exposure is completed prior to undertaking research into the health outcomes and possible interventions. Three main themes have been identified.

Improve the measurement of noise

The studies identified in the systematic review did not directly measure wind turbine noise at participants' homes. People's exposure to wind farm noise was assessed based on how far they lived from the nearest wind turbine (proximity) or by using mathematical models to estimate the level of sound where they lived. However, it is difficult to estimate the level of noise from wind farms in the presence of background noise.

Where consistent associations were found between estimated wind turbine noise and health-related outcomes (such as annoyance), it was not possible to tell whether noise was driving the association, or whether the association could be explained by one or more other factors that are more common among people living in close proximity to wind farms (such as attitude to, visibility of or economic benefit from wind farms).

The Reference Group considers that further research is required to characterise wind turbine noise (audible, low frequency and infrasound) at distances from the turbines ranging from 500 m to 3 km and beyond, in different terrains and under varying weather conditions. These outcomes may inform whether a 'wind turbine signature' can be developed and validated as a model of wind turbine noise.

Infrasound is considered by some to be an important component of the noise from wind farms. The Reference Group considers that there is a need to develop standardised methods to measure infrasound indoors and outdoors, at various distances from a wind turbine (at distances ranging from 500 m to 3 km and beyond). This would ensure there is consistency in the measurement of infrasound from wind turbines and aid interpretation of the body of evidence on the impacts of wind turbine noise.

Field studies to establish the characteristics of noise that are exclusive to wind turbine origins (if any), and to consider how wind turbine noise varies diurnally, in different terrains, under different weather conditions and with further increases in distance from wind turbines, would be a useful approaches to address this issue.

Examine the relationship between wind turbine noise and health or health-related effects

All the studies identified in the systematic component of the independent review used self-reported measures of health outcomes to determine whether there was any association with exposure to wind turbine emissions. Given the lack of objective health measurements in these studies, information bias cannot be excluded as an explanation for any apparent association. In addition, the measurement of health-related effects such as annoyance, sleep disturbance and mental health in relation to wind turbine proximity lacked the consistent use of validated questionnaires.

There is a need to conduct field studies which consider objectively measured physiological and biochemical characteristics (including sleep) along with an individual's self-reported physical and psychological status (including annoyance). These measures should be compared to objectively recorded noise from wind turbines (measured inside and outside of their residence) and/or exposure to simulated wind turbine noise generated by a speaker.

Laboratory studies would also be useful to examine the effects of validated wind turbine noise on objectively measured physiological and biochemical characteristics. These findings could then be considered in parallel to comparable field studies.

Investigate the social and environmental circumstances

The Reference Group recommend further investigation of the broader social and environmental circumstances that influence annoyance, sleep disturbance, quality of life and health effects that are reported by some residents living in close proximity to wind farms.

Factors that influence changes to health effects and health-related outcomes may include a person's expectations of peace, perceived loss of control, aesthetics and impacts on visual landscape, impacts on land values, uneven distribution of financial benefits and exposure to other noise sources (e.g. road traffic and wind noise).

Further research would improve the understanding of the potential confounding or modifying effect of these factors on the relationship between objectively recorded exposure to validated wind turbine noise and:

an individual's self-reported physical and psychological status (including annoyance); and

an individual's objectively measured physiological and biochemical characteristics.

This could be achieved through a program of psychosocial research to investigate, develop and test interventions that might reduce the impacts of wind farm developments on nearby residents. This research may assist in developing possible policy or consultative interventions that may address the above broader factors, and thereby reduce the reported health and health-related effects of wind turbines.

Glossary

Acoustics: The science that deals with the study of the generation, transmission and reception of sound, ultrasound and infrasound.

Aerodynamic sound: For wind turbines, the sound generated by the interaction of the blade trailing edge, tip or surface with air turbulence.

Annoyance: An unpleasant mental state characterised by effects such as irritation and distraction from one's conscious thinking.

Association:* Statistical dependence between two or more events, characteristics or other variables.

Background evidence: Includes evidence obtained from related fields that support the association between an exposure of interest and an adverse health effect (parallel evidence) and evidence for a mechanism by which an exposure of interest may cause a particular health outcome of interest (mechanistic evidence); the mechanism may be biological, chemical or mechanical.

Bias:* The effect of an error in the design of a study or an error or problem in the collection, analysis, reporting, publication or review of study data that leads to untrue results.

Chance:* The probability that an event will happen[#] or, in a phrase such as "happened by chance", the occurrence of events in the absence of any obvious intention or cause.

Confounding:* 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.

Cross-sectional study:* A study that examines the relationship between diseases (or other health-related characteristics) and other variables as they exist in a defined population at one particular time.

Decibel: 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 linking an exposure with a health outcome of interest.

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.

Electromagnetic radiation: Radiation that is a combination of electric and magnetic waves (such as X-rays, ultraviolet rays, infrared rays, visible light and radio waves) transmitted in a wave-like pattern as part of a continuous spectrum of radiation.

Emission: For wind farms, recognised emissions include noise (including infrasound and low-frequency sound), shadow flicker and electromagnetic radiation.

Epidemiology: The study of the patterns, causes, and effects of health and disease conditions in human populations.

Epilepsy: A neurological condition marked by sudden recurrent episodes of sensory disturbance, loss of consciousness, or convulsions, associated with abnormal electrical activity in the brain.

Exposure: For this review, exposure relates to being in the vicinity of wind farm emissions.

Frequency: The number of sound waves or cycles passing a given point per second; measured in cycles per second and reported in Hertz (1 Hertz = 1 cycle per second).

Grey literature: Multiple document types and literature produced by government, academia, business, and other organisations in electronic or print format. Grey literature is not always peer reviewed and is not controlled by commercial publishing.

Health outcome: A change in health status.

Health-related outcome: A change in a factor that may be an indicator of health or may affect health if it persists (e.g. poor sleep quality).

Hertz: A measure of frequency. 1 cycle per second = 1 Hertz.

Infrasound: A term used to describe sound in the frequency range lower than 20 Hertz.

[#] The International Epidemiological Association definition⁴⁶ states 'possibility' rather than 'probability'. However, for the purposes of the systematic review, 'probability' was preferred.

Low-frequency sound: Sound that falls within the frequency range of 20 to 200–250 Hertz.

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. Also called 'blinding'.

Mechanical sound: For wind turbines, the sound produced by the interaction of electrical and rotational parts such as gearbox and generator.

Narrative review: A literature review that is conducted without a pre-defined protocol or method.

Noise: Unwanted sound or a combination of sounds.

Participants: People who have taken part in a trial or study, or have responded to a survey questionnaire or interview.

Peer-reviewed literature: Published literature that, before it was published, was reviewed critically by other people in the same field of research and revised in response to the critical review as a condition of publication.

Prevalence:* A measure of occurrence or disease frequency that refers to the proportion of individuals in a population who have a disease or condition.

Psychology: The scientific study of mental functions and behaviours.

Quality of life: A person'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.

Selection bias:* Distortions in outcomes that result from the procedures used to select participants and from factors that influence participation in a study.

Self-report: Information on a person's history or personal characteristic that a person themselves provides, generally from memory.

Shadow flicker: The flickering effect caused when rotating wind turbine blades intermittently cast shadows over neighbouring properties as they turn.

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 pressure level: A measure of the sound pressure of a sound relative to a reference value, measured in decibels (dB).

Sound: An energy form that travels from a source in the form of waves or pressure fluctuations, transmitted through a medium (e.g. air, water), and received by a receiver (e.g. human ear).

Systematic literature review: A process that provides a transparent and reproducible 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.

Tinnitus: The perception of sound within the human ear (ringing in the ears) when no actual sound is present.

Tonality:** Noise containing a prominent frequency and characterised by a definite pitch.

Wind farm: A collection of wind turbines.

Wind turbine: A device that uses kinetic energy from the wind to produce electricity.

* Adapted from the International Epidemiological Association *Dictionary of epidemiology*.⁴⁶

** Definition from NSW industrial noise policy.³¹

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