BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF SOUTH DAKOTA

IN THE MATTER OF THE APPLICATION BY PREVAILING WIND PARK, LLC FOR A PERMIT FOR A WIND ENERGY FACILITY IN BON HOMME, CHARLES MIX, AND HUTCHINSON COUNTIES, SOUTH DAKOTA, FOR PREVAILING WIND PARK ENERGY FACILITY

SD PUC DOCKET EL18-026

PRE-FILED SUPPLEMENTAL DIRECT TESTIMONY OF DR. MARK ROBERTS
ON BEHALF OF PREVAILING WIND PARK, LLC

August 10, 2018

I. INTRODUCTION AND QUALIFICATIONS

Q. Please state your name, employer, and business address.

A. My name is Dr. Mark Roberts. I am employed by Exponent, Inc. (“Exponent”), and my office is located at 525 West Monroe Street, Suite 1050, Chicago, Illinois 60661.

Q. Please describe your educational and professional background.

A. I am a Principal Scientist in the Chicago office of Exponent, a scientific research and consulting company headquartered in Menlo Park, California. I have worked at Exponent since November 2003.

Prior to working at Exponent, I held a series of positions with advancing responsibility in the areas of public health, occupational medicine, and academia. I was employed at the Oklahoma State Department of Health from 1972 to 1990 and held a series of positions culminating in my appointment as the State Epidemiologist, a post that I held from 1979 to 1982, followed by the position of Consulting Medical/Environmental Epidemiologist from 1983 to 1990. In both of these capacities, I directed epidemiologic investigations consisting of a broad range of health concerns, from food-borne outbreaks to cancer clusters.

I was a faculty member of the Department of Preventive Medicine at the Medical College of Wisconsin from 1990 to 1997, and I completed my tenure as Associate Professor and Acting Chairman of the Department. I have also served as Corporate Medical Director for several global companies. While on faculty at the Medical College of Wisconsin in Milwaukee, Wisconsin, I was contract Medical Director for Wisconsin Centrifugal, a foundry in Waukesha, Wisconsin. In this role, I supervised the health monitoring programs, both company-mandated and Occupational Safety and Health Administration (“OSHA”) required, in addition to the day-to-day clinical aspects of the employee health service. My responsibilities included biological surveillance of employee population as well as worksite reviews and inspections.

I earned an M.S. in Education in 1972, an M.P.H. in Epidemiology and Biostatistics in 1974, and a Ph.D. in Epidemiology and Biostatistics in 1979. I completed medical school in 1986, an internship in Family Medicine in 1987, and a residency/fellowship in Occupational and Environmental Medicine in 1990.

I am a Fellow of the American College of Occupational and Environmental Medicine. I have unrestricted licenses to practice medicine in Oklahoma and Wisconsin. In addition to my employment experience, I am a past member (2000–2007, 2008–2011) of the Board of Directors, Vice President (2013-2014), and President (2015-2016) of the American College of Occupational and Environmental Medicine in Arlington Heights, Illinois. I have been a member of the Board of Directors of Vysis, Inc. in Downers Grove, Illinois and the Board of Scientific Counselors for the Agency for Toxic Substances and Disease Registry in Atlanta, Georgia. In addition, I have served as an active participant on numerous state and national professional committees. My statement of qualifications is attached as Exhibit 1.

Q. Did you previously provide prefiled testimony in this docket?

A. No.

II. PURPOSE OF TESTIMONY

Q. What is the purpose of your Direct Testimony?

A. The purpose of my testimony is to (i) give an overview of public health and epidemiology principles implicated by an inquiry into the health effects of wind turbines; (ii) generally assess health claims that have been attributed to wind turbines in light of the peer-reviewed and published scientific literature; and (iii) specifically address health concerns relating to infrasound, vertigo, and "vibroacoustic disease" raised during the public input hearing for the proposed Prevailing Wind Park ("Project").

Q. Please provide a brief summary of the opinions you are offering in your Direct Testimony.

A. My opinions can be summarized as follows:

1. Wind turbines, as a cause of specific adverse health effects, have not been proven by peer-reviewed, published scientific literature;
2. The tried and true scientific method of developing a hypothesis, testing that hypothesis, publishing the results and having others attempt to repeat the research has not demonstrated that wind turbines are a causative agent of specific adverse health effects;
3. An accumulation of anecdotal testimony from persons living near a wind turbine does not constitute an epidemiological study and is not sufficient to determine causation;
4. Several well-respected governmental agencies charged with protecting public health have evaluated the available evidence and have concluded that wind turbines are not a cause of adverse health effects; and
5. The published literature has shown some association between wind turbine noise emissions and annoyance. However, the level of annoyance is often more closely tied to visual impacts and attitudes regarding wind turbines than to actual sound levels. While annoyance is at times associated with various symptoms, it is not a disease. Instead, those varied symptoms represent a normal physiological response.

Q. What exhibits are attached to your Direct Testimony?

A. The following Exhibits are attached to my Direct Testimony:

- Exhibit 1: Statement of Qualifications.
- Exhibit 2: Australian National Health and Medical Research Council (2010). *Wind Turbines and Health: A Rapid Review of the Evidence*. This report was updated in 2014 and 2015.
    - Exhibit 2a: Australian National Health and Medical Research Council (2014). *Review of Additional Evidence for NHMRC*

    - *Information Paper: Evidence on Wind Farms and Human Health – Final Report*.

    - Exhibit 2b: Australian National Health and Medical Research Council (2015). *NHMRC Statement: Evidence on Wind Farms and Human Health*.

    - Exhibit 2c: Australian National Health and Medical Research Council (2015). *Systematic Review of the Human Health Effects of Wind Farms*.

- Exhibit 3: French National Agency for Food Safety, Environment and Labor ("ANSES") (2017). *ANSES Opinion regarding the expert appraisal on the "Assessment of the health effects of low-frequency sounds and infrasounds from wind farms."*
- Exhibit 4: Wisconsin Wind Siting Council (2014). *Wind Turbine Siting – Health Review and Wind Siting Policy Update*.
- Exhibit 5: Joseph Rand and Ben Hoen (2017). *Thirty Years of North American wind energy acceptance research: What have we learned? Energy Analysis and Environmental Impacts Division*, Lawrence Berkeley National Laboratory, Electricity Markets and Policy Group.
- Exhibit 6: Public Service Commission of Wisconsin (2015). *Review of Studies and Literature Relating to Wind Turbines and Human Health. Prepared for the Wisconsin State Legislature*.
- Exhibit 7: Massachusetts Departments of Environmental Protection and Public Health (2012). *Wind Turbine Health Impact Study: Report of the Independent Expert Panel*.
- Exhibit 8: Letter, Kim Malsam-Rysdon, Secretary of Health, South Dakota Department of Health (Oct. 13, 2017), *In the Matter of the Application by Crocker Wind Farm, LLC for a Permit of a Wind Energy Facility and a 345 kV Transmission Line in Clark County, South Dakota, for Crocker Wind Farm*,

Docket No. EL17-055. available at: https://puc.sd.gov/commission/dockets/electric/2017/el17-055/DK4.pdf.

III. OVERVIEW OF PUBLIC HEALTH AND EPIDEMIOLOGY PRINCIPLES

Q. What is the practice of Occupational and Environmental Medicine?

A. Occupational and Environmental Medicine is a medical subspecialty that is recognized by the American Board of Medical Specialties and is one of the population-based specialties of Preventive Medicine. Specialists in this area are physicians with advanced training in prevention-based medical care of populations. Occupational and Environmental Medicine focuses on environment/health interactions, including workplace-related illnesses and injuries, and workplace effects on non-work-related conditions. Occupational and Environmental Medicine physicians are also trained to assess the possible causes of a worker's health condition. This specialty draws heavily on the key tenets of epidemiology, biostatistics, industrial hygiene, risk assessment, and toxicology. I relied extensively on my training in this field to reach my conclusions noted above.

Q. What is epidemiology?

A. Epidemiology is the study of distribution and dynamics of factors in populations. It is considered the cornerstone methodology in all of public health research, and is highly regarded in evidence-based medicine for identifying risk factors for disease and determining optimal treatment approaches to clinical practice. Epidemiology is the scientific study of factors affecting the health and illness populations, and in this capacity, it serves as the foundation and logic of interventions made in the interest of the public's health and preventive medicine.

Epidemiological studies are generally categorized as descriptive, analytic (aiming to examine associations and commonly hypothesized causal relationships), and experimental (a term often equated with clinical or community trials of treatments and other interventions). Case reports and case series are not epidemiological studies because they have no comparison group. Epidemiology addresses whether an agent can be linked to a cluster of cases, but not whether an agent caused a specific individual's disease. So while epidemiologists cannot diagnose individuals, they can establish the defining characteristics of clusters of illnesses, such as the point in time at which a given pathogen from a specific source began to cause problems and when it stopped.

In this case, epidemiologic methods are the appropriate tool to guide the determination of whether wind turbines are the cause of disease in people living nearby. The practice of medicine, in contrast, is devoted to preventing, alleviating or treating diseases and injuries in individuals. Concerned with disease in populations, epidemiology is used to determine what is sometimes called "general causation." However, it does not establish the cause of an individual's disease, which is sometimes referred to as "specific causation."

Q. How are "epidemiology methods" used to determine causation?

A. Epidemiology is the basic methodology used to characterize a health condition among groups of people. Epidemiology incorporates the methods needed to identify associations and, ultimately, is used to determine causation. Epidemiological research starts with a scientific hypothesis, which is then investigated and the information is critically reviewed and shared with the scientific community by being published. The totality of this research then forms the material to answer the question, "Is there an association between exposure and the health condition?" Mere association is not the same as causation. Two things can be associated, but one does not necessarily cause the other. Determination of causation is a higher level of data assessment including assessment of the totality of published literature relevant to the subject and requires transparent analysis of the data before it is concluded that the observed association is actually causal. Not all associations turn out to be causal. If the data is not carefully reviewed, a causal relationship may be erroneously assigned to the relationship, which is why peer review is so critical to the process.

Q. Can you provide more detail about what the terms "association" and "causation" mean, as used in epidemiology?

A. There have been clinical observations (case reports and series) that stimulated a number of now classic epidemiology research efforts identifying important associations and ultimately the determinants of causal relationships. Case studies and case reports, however, cannot be used to determine causation. A causal association can only be established by the evaluation of well-designed and executed epidemiologic studies that have undergone peer review, in addition to research from other disciplines (e.g., exposure, toxicology). A landmark discussion of the process of moving from a disease being associated with a risk factor to concluding the association is causal was put forth by Sir Austin Bradford Hill in 1965. It was during this time that a number of papers, including the Surgeon General Report in 1964, began to more formally delineate the scientific process for concluding that an exposure is causally related to a disease.

The process of moving from "association" to "causation" is a complex process, but a key point emphasizing the process was made by Sir Bradford Hill when he started his discussion of causation by stating:

> Disregarding then any such problem in semantics we have this situation. Our observations reveal an association between two variables, perfectly clear-cut and beyond what we would care to attribute to chance. What aspects of that association should we especially consider before deciding that the most likely interpretation of it is causation?

Hill 1965. Sir Bradford Hill's nine criteria for causation have been described in a number of ways. They are commonly referred to as strength, consistency, specificity, temporality, biological gradient, plausibility, coherence, experiment, and analogy. Hill 1965.

Q. Are Hill's nine criteria still valid today?

A. Yes. The criteria presented by Sir Bradford Hill are most often referred to as the guidance used to progress in a scientifically defensible manner from a claim of association to one of causation.

Q. Please describe some recent examples of how initial studies moved from association to causation and the ultimate results of those research efforts.

A. Beyond the classic studies of lung cancer and smoking, we now know that there is an increase in lung cancer from secondhand smoke and from radon exposures. It seems that not a week goes by that we do not hear about a new disease association often related to cancer or heart disease. Take butter for example, it has fallen in and out of favor multiple times over the years. It is only a "proven causation" when the science provides clear documentation of the magnitude of the association.

Q. Why is it important that scientific research be published in peer-reviewed scientific journals?

A. In this computer age, we are awash in "information" without clear evidence of its validity. With the advent of the internet, views, opinions, hypotheses, and mere speculation can be made to appear just as valid as sound science, but without the rigor of critical and objective review. For example, an internet search on August 2, 2018 using the terms "wind turbine health" returned 14.2 million results. Thus, when making decisions about potential impacts to human health, such as determining whether wind turbines are a cause of a clinically recognized human condition or disease, it is vitally important that we rely on sound science and recognized scientific methods, as supported by peer-reviewed scientific articles. The act of submitting an article for publication in a peer-reviewed journal indicates that there is a rigorous process of review and analysis to assess its scientific merit, its contribution to the scientific body of knowledge in the specific area, and its pertinence to the area covered by the journal. The growth of research and the number of researchers has increased the competition for publication space in journals worldwide. Unfortunately, this growth has also led to publication resources that are not as rigorous in their review process, which can result in opinion pieces being published with the appearance of a science basis (i.e., pseudo-science).

Today, manuscripts get reviewed at the journal editor level and those that are judged worthy of consideration (approximately 25 percent) are sent to the peer review panel members, and roughly 10 percent of those get accepted for inclusion in the journal. The peer review publication process carefully scrutinizes the major aspects of the manuscript down to checking the numbers in the tables. Wind turbines have generated a large amount of interest and information as evidenced by the millions of results an internet search of “wind turbine health” will yield. However, volumes of unscientific material should not be taken as proof of causation. Many of the opinions voiced are not supported by review using a rigorous application of the scientific method of discovery.

Q. What is the scientific method of discovery?

A. In the process of an idea or an observation being assimilated into the science knowledge base, it must first come to someone’s attention. That can be an astute observation or a series of events that catches the attention of a science-minded individual (a researcher). The individual weighs the observation against what they know and makes a decision to investigate the observation further.

The attention of the scientific community is alerted to the opinion based on an observation, which is usually in the form of case reports or case series. It should be recognized by all that case reports and case series are merely observations. Case reports or case series are seldom if ever accepted for publication by the leading science journals, partially due to the fact that case reports are seen as observations without quantification or other indication of validity. This quantification or validation comes from the careful scientific study of the opinion using well-designed epidemiologic studies and sound scientific methods.

A well-designed epidemiologic study allows the researcher to make comparisons between those with and those without the condition or effect in order to determine if an association is apparent. That is, those that are "exposed" are more likely to manifest the health condition than the "non-exposed" or the "expected number." A good example of this is the investigation of a foodborne outbreak where epidemiologists compare the rate of occurrence of objective indications of illness in those persons who ate the suspect food item to the rate of similar illness among those that did not eat the suspect food item. The key to this step in the scientific method is that there is a comparison group to compare objective signs of illness. A comparison group is not present in a case report or a series, where the researcher is speculating (also known as a hypothesis) but cannot make a statement about the risk (strength of the association). In an epidemiological study, a method of comparison is included that will allow the researcher to evaluate the strength of the association. Furthermore, one epidemiological study does not prove causation. The researcher who publishes the first epidemiological study is the one that alerts his or her peers and hopefully stimulates them to do more research to explore the association. Once a sufficient body of knowledge has been produced, then the question of causation can be addressed either by governmental agencies or professional organizations.

Thus the scientific knowledge base is strengthened by the collective work of different researchers, using different epidemiological methods, in different study populations combining their research. This body of research around the original observation is then evaluated to see if there is sufficient scientific information to support that a cause for the condition has been identified and is scientifically justifiable.

Q. Why utilize scientific methodology when there are case studies and/or personal testimonials asserting that wind turbines can cause adverse health effects?

A. The scientific methodology is an accepted process used to evaluate epidemiologically-based evidence, and make sound, scientifically supportable decisions. There have been numerous examples where an agent first thought to be the cause of a disease was not confirmed to be so as a result of the scientific process of hypothesis generation, research, and peer review. For example, in the following instances associations between an exposure and disease were disproven: coffee and pancreatic cancer (ACS 2011); silicone breast implants and autoimmune diseases (Hölmich et al. 2007); saccharin and bladder tumors (NCI 2009); Bendectin and birth defects (McKeigue et al. 1994). In some instances, an alternative cause is proven: spicy food and ulcers (turns out many are caused by bacteria) (NIH 2010). Clearly, initial observations and hypotheses are not always supported by more thorough scientific investigation. Even strongly held beliefs by groups of people do not provide proof of causation and at times can be detrimental to the scientific process and to public health. A timely example of such a situation is the current belief by some that immunizations cause autism.

The multiple governmental reviews and reports of public health officials show that concerns related to wind turbines' potential for adverse health effects have been and are being taken quite seriously. However, the subjective, non-specific complaints, which show a great deal of variability, are simply insufficient evidence that wind turbines are the cause of adverse human health effects.

IV. ASSESSMENT OF HEALTH CLAIMS RELATED TO WIND TURBINES

Q. What have government agencies concluded about wind turbines?

A. Several agencies (state, national and international) have concluded that wind turbines are not associated with adverse health effects in humans. Following are a few examples of those studies:

- In 2010, the Australian National Health and Medical Research Council conducted a review of the evidence and concluded that "wind turbines do not pose a threat to health if planning guidelines are followed." Exhibit 2. The results of the 2010 Australian National Health and Medical Research Council study were confirmed in subsequent studies. In 2015, the

NHMRC concluded that there is no consistent evidence that wind farms cause adverse health effects in humans. *See* Exhibit 2a and Exhibit 2b. The 2014 NHMRC Final Report found no reliable evidence that wind turbine emissions cause adverse health effects by biological pathways. Exhibit 2c.

- In 2017, the French National Agency for Food Safety, Environment and Labor ("ANSES") conducted a review of the available experimental and epidemiological data, and did not find any adequate scientific arguments for the occurrence of health effects related to exposure to noise from wind turbines, other than disturbance related to audible noise and a nocebo effect, which can help explain the occurrence of stress-related symptoms experienced by residents living near wind farms. Exhibit 3.
- In 2014, the Wisconsin Siting Council concluded that no association between wind turbines and health effects has been scientifically shown. Exhibit 4.
- Researchers at the Lawrence Berkeley National Laboratory similarly found no link between wind turbines and adverse health effects. Exhibit 5.
- The Public Service Commission of Wisconsin (2015) concluded that: "Presently, the recent literature on this subject continues to reach conclusions similar to those identified in the 2014 WSC report. The studies have found an association between exposure to wind turbine noise and annoyance for some residents near wind energy systems. Some studies show this as a causal relationship between wind turbines and annoyance. There is more limited and conflicting evidence demonstrating an association or a causal relationship between wind turbines and sleep disturbance. There is a lack of evidence to support other hypotheses regarding human health effects caused by wind energy systems." Exhibit 6.
- An independent expert panel for Massachusetts (2012) found that there was limited evidence supporting an association between wind turbines and annoyance or possible sleep disturbances. However, the panel

concluded that “there is insufficient evidence that the noise from wind turbines is *directly* (*i.e., independent from an effect on annoyance or sleep*) causing health problems or disease.” Exhibit 7 (italics in original).

Q. You conducted a review of the peer literature on health effects attributable to sound. What did it show as it relates to sound generated by wind turbines?

A. My analysis and review of the peer reviewed, published literature did not identify scientific works that provide objective support for the claims being made regarding wind turbines. The peer reviewed, scientific research involving the health effects of sound levels (from various sources) is extensive. Research on health effects associated with human exposure to sound has evolved from the study of physical damage (e.g., hearing loss) to the study of psychological effects and other non-specific physical symptoms. Research has focused on both the frequency and amplitude of sound, within and outside of the audible range of human hearing.

Most of the available literature examines noise exposures at the workplace, as high levels of noise exposure are one of the most established forms of occupational injury. Noise exposures outside the workplace have not been studied as extensively yet may be just as damaging (e.g., chain saws, leaf blowers, power saws and lawn mowers). However, there has been research on exposures to highway traffic noise, commercial airport noise, and a variety of other community noise sources that can provide valuable insight into the evaluation of sound generated by the operation of wind turbines. This body of research has identified a number of health-related associations with high levels of industrial sound in the workplace. However, this same science has not identified a causal link between any specific health condition and exposure to the sound patterns generated by contemporary wind turbine models, perhaps because they generate far lower decibel levels than most vocational sources. This same science has determined that there is a range of sounds (some would say noise) that is clearly described by some as annoying. There have been illnesses, symptom complexes, and other health events attributed to wind turbines. This is to be expected given the circumstances and emotions that often surround the presence of wind turbine farms. This is a common phenomenon that is associated with activities that may be perceived as a social disruption or conflict of personal rights by a subset of the population.

Despite the attribution of various health events to wind turbines, there has not been a specific health condition documented in the peer-reviewed published literature to be recognized by the medical community or professional societies as a disease caused by exposure to sound levels and frequencies generated by the operation of wind turbines.

Q. Has the State of South Dakota addressed claims of an association between wind turbines and health effects?

A. The State of South Dakota has not specifically studied alleged health effects and wind turbines. However, the Department of Health was asked to opine on the issue in another docket, *In the Matter of the Application by Crocker Wind Farm, LLC for a Permit of a Wind Energy Facility and a 345 kV Transmission Line in Clark County, South Dakota, for Crocker Wind Farm*, Docket No. EL 17-055. The South Dakota Secretary of Health, Kim Malsam-Rysdon, submitted a letter consistent with my testimony (Exhibit 8):

> The South Dakota Department of Health has been requested to comment on the potential health impacts associated with wind facilities. Based on the studies we have reviewed to date, the South Dakota Department of health has not taken a formal position on the issue of wind turbines and human health. A number of state public health agencies have studied the issue, including the Massachusetts Department of Public Health[1] and the Minnesota Department of Health[2]. These studies generally conclude that there is insufficient evidence to establish a significant risk to human health. Annoyance and quality of life are the most common complaints associated with wind turbines, and the studies indicate that those issues may be minimized by incorporating best practices into the planning guidelines.

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[1] http://www.mass.gov/eea/docs/dep/energy/wind/turbine-impact-study.pdf

[2] www.health.state.mn.us/divs/eh/hazardous/topics/windturbines.pdf

Q. Based on your review of the available scientific literature, are there potential adverse health effects from the sound of wind turbines?

A. No, because the levels of sound and infrasound from wind turbines are significantly lower than those that have been shown to cause harm. Substantial research has been done on sound level exposures to humans. This body of scientific research has identified a number of health-related links to high level industrial sound in the workplace. For example, OSHA has set a limit of 90 A-weighted decibels (“dBA”) based on a finding that exposure to levels of noise above 90 dBA in the workplace can cause hearing damage and set an 85 dBA level as the set point of initiation of a hearing protection program in the workplace. However, as I noted earlier, this same science has not identified a causal link between any specific health condition and exposure to the sound patterns generated by contemporary wind turbine models. In addition to my own conclusions, several other respected organizations and agencies have reached similar conclusions, as I have described previously herein.

V. SPECIFIC HEALTH ISSUES RAISED AT PUBLIC INPUT MEETING

Q. Did you attend the public input meeting that was held on July 12, 2018?

A. No, but I have been made aware that the following health concerns were raised by commenters at that meeting:

- Infrasound;
- Vertigo; and
- “Vibroacoustic Disease”.

In addition, I understand that some members of the public expressed concern that potential health impacts could occur and/or be amplified because Prevailing Wind Park, LLC (“Prevailing Wind Park”) proposes to use turbine models that are in excess of 500 feet. I will address each of these issues in more detail below.

Q. Please describe the concern related to infrasound as you understand it.

A. Based on comments made at the public input hearing, I understand that some commenters expressed concern regarding the potential for infrasound to generally cause negative health consequences.

Q. What is infrasound?

A. Infrasound, sometimes referred to as low frequency sound, is sound that is between 0 hertz ("Hz") and 20 Hz. Although the human hearing threshold has been found to be as low as 4 Hz in an acoustic chamber, a level of 20 Hz is commonly considered the low end of the range of hearing.

Q. What is your response to comments regarding infrasound?

A. I am not aware of any reliable evidence providing any link between infrasound and adverse health effects. Multiple health experts have confirmed this point. Specifically, infrasound at frequencies lower than 20 Hz are audible at very high levels (110+ dBA), and these sounds may occur from man-made but also many natural sources, such as meteors or volcanic eruptions. Anthropogenic (i.e., human-caused) sources, which often are the predominant type of sound, can also generate infrasonic noise and include machinery, ventilation, large combustion processes and naturally occurring winds.[3] In addition, heart sounds are in the range of 27 to 35 dBA at 20-40 Hz[4] and lung sounds are reported in the range of 5-35 dBA at 150-600 Hz.[5] Note that these sources are in the range of sound produced by wind turbines. Thus, infrasound – both man-made and naturally-occurring – are all around us.

Q. Please describe the concern related to vertigo as you understand it.

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[3] Berglund, B., Hassmen, P., and Job, R. F. (1996). Sources and effects of low-frequency noise. *Journal of the Acoustical Society of America*. 99(5), (2985-3002); Leventhall, G. (2007). *What is infrasound?* 93(1-3), (130-137); Sienkiewicz, Z. (2007). Rapporteur report: Roundup, discussion and recommendations. *Progress in Biophysics and Molecular Biology*. 93(1-3), (414-420).

[4] Sakai, A., Feigen, L. P., and Luisada, A. A. (1971). *Frequency distribution of the heart sounds in normal man.* Cardiovascular Research. 5(3), (358-363).

[5] Fiz, J. A., Gnitecki, J., Kraman, S. S., Wodicka, G. R., and Pasterkamp, H. (2008). Effect of body position on lung sounds in healthy young men. 133(3), (729 -736).

A. As I understand the comments at the public input hearing, there was a concern expressed that the operation of wind turbines may cause (or has caused) vertigo in some individuals. Vertigo is the sense that your environment is spinning. It is a form of dizziness. Vertigo is caused by problems in the brain or inner ear, including sudden head movements, inflammation within the inner ear due to a viral or bacterial inner ear infection, Meniere's disease, tumors, decreased blood flow to the base of the brain, multiple sclerosis, head trauma and neck injury, migraine headaches, or complications from diabetes.

Q. What is your response to comments regarding vertigo?

A. Based on my review of the scientific literature, I am not aware of any causal relationship between wind turbines and vertigo. Published population-based studies indicate that dizziness (including vertigo) affects between 15 percent and 20+ percent of adults yearly. Vertigo associated with the inner ear accounts for about a quarter of dizziness complaints. Studies indicate that the prevalence rises with age and is about two to three times higher in women than in men. As noted above, there are many health conditions associated with vertigo, but there appears to be no single cause, and there has be no scientific study associating wind turbines and the development of vertigo.[6]

Q. Please describe the concerns related to "vibroacoustic disease" as you understand them.

A. Based on my review of the comments made at the public input hearing, I understand that some commenters expressed concern about the Project's potential to cause "vibroacoustic disease," a condition asserted to exist for aircraft maintenance workers by certain researchers in Portugal.

Q. What is your response to comments regarding vibroacoustic disease?

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[6] The Epidemiology of Dizziness and Vertigo, Handbook of Clinical Neurology, 2016; 137:67-82 (Chapter 5).

A. Vibroacoustic disease has primarily been studied in aircraft maintenance workers and has been described by certain Portuguese researchers as a chronic, progressive, medical condition where there is a thickening of blood vessels which impedes the normal flow of blood and there is thickening of the membrane around the heart and of the heart valves. Aircraft maintenance workers routinely work in environments with high-intensity sound greater than 110 dBA, coupled with low-frequency sounds below 100 Hz, which are commonly encountered when working in the vicinity of aircraft.

A majority of the published work involving vibroacoustic disease has originated from certain researchers in Portugal and has not been significantly replicated by other research groups. Dr. Alver-Pereira (the primary researcher) has testified that she has concerns about the potential of an association between the sound of wind turbines and vibroacoustic disease, but she has not reconciled the difference in the intensity of the low frequency sound she has studied in aircraft maintenance workers and the low intensity of sound produced by wind turbines. In addition, Dr. Alver-Pereira has not performed a scientific sound study of wind turbine noise in her work on vibroacoustic disease. Based on my work and review of reliable scientific literature, I am not aware of any link between wind turbines and what Dr. Alver-Pereira describes as vibroacoustic disease.

Q. With respect to concerns regarding turbine height, does the fact that Prevailing Wind Park proposes to use a turbine model over 500 feet alter any of the opinions or conclusions you have provided in this testimony?

A. No, the proposed turbine model's height does not alter my opinions or conclusions.

Q. Do you have any other responses to comments made at the July 12, 2018, public input meeting?

A. Yes. I understand that Dr. Jamin Hübner, who holds a Th.D. in Systematic Theology,[7] submitted what he termed "A Partial Bibliography of Academic Literature Demonstrating Adverse Health Effects of Industrial Wind Turbines." In general, the submission is an aggregation of statements taken from articles and provides little synthesis of the findings of the articles. As I have previously discussed in this testimony, numberous state, national, and international governmental bodies have concluded that wind turbines are not associated with a specific adverse health effect in humans. Dr. Hübner's document is not an accurate representation of the current state of the science in this area. A more detailed review of the articles which Dr. Hübner has selectively chosen, and from which he has selectively pulled quotes, illustrates that these articles often do not support Dr. Hübner's stated conclusion that the literature "demonstrate[s] adverse health effects of industrial wind turbines." Rather, this literature concludes the opposite.

For example, Dr. Hübner's document refers to a report I co-authored for the Wisconsin Public Service Commission in 2009 related to low frequency sound; however, the document quotes the report out of context and, as such, misrepresents the conclusion we reached. The portion of our literature review quoted by Dr. Hübner summarizes diverse studies generally related to low frequency sound and the workplace. If Dr. Hübner had read further in the literature review, he would have seen the following discussion:

> The literature, both scientific and lay, clearly indicates the diversity of concerns regarding the presence of wind turbines near residences and communities. The science of sound is robust and has identified a number of health-related links to high level industrial sound in the workplace. *This same science has not identified a causal link between any specific health condition and exposure to the sound patterns*

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[7] *See* http://jwc.edu/teams/jamin-hubner/ (last accessed August 10, 2018).

> *generated by wind turbines of the type used today, perhaps because they generate far lower decibel levels than most vocational sources*. However, the same science has determined that there is a range of sounds (some would say noise) that is clearly described by some as annoying. The process of being annoyed is a universal response that is not specific to wind turbines. The nonspecificity of annoyance leads to confusion and concern that the peer reviewed published scientific literature has not been able to adequately clarify.

In addition, our literature review concluded: "Based on the literature review that was conducted for this white paper, ***there was not any scientifically peer-reviewed information found demonstrating a link between wind turbines and negative health effects***." As such, Dr. Hübner's citation of my literature review as support for his assertion that wind turbines cause negative health impacts is misplaced.

VI. CONCLUSION

Q. Does this conclude your Direct Testimony?

A. Yes.

Dated this 10th day of August, 2018.

Mark A Roberts MD

Dr. Mark Roberts

CURRICULUM VITAE

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EDUCATION

1967-69	A.S.	Pre-Veterinary Medicine. Murray State College, Tishomingo, OK
1969-71	B.S.	Zoology. University of Oklahoma, Norman, OK
1971-72	M.Ed.	Higher Education, Student Personnel Services, University of Oklahoma, Norman, OK
1972-74	M.P.H.	Biostatistics and Epidemiology. University of Oklahoma, Health Sciences Center, Oklahoma City, OK
1974-79	Ph.D.	Biostatistics and Epidemiology. University of Oklahoma, Health Sciences Center, Oklahoma City, OK
1982-86	M.D.	College of Medicine. University of Oklahoma, Health Sciences Center, Oklahoma City, OK

POST GRADUATE TRAINING

1986-87	Intern, Family Medicine, University of Oklahoma, Health Sciences Center, Oklahoma City, OK
1987-89	Resident Occupational Medicine Program University of Oklahoma, Health Sciences Center, Oklahoma City, OK
1989-90	Research Fellow in Occupational Medicine Program University of Oklahoma, Health Science Center Oklahoma City, OK
1990	American College of Occupational Medicine, Medical Review Officer Training Course for Urine Drug Testing, October 12-13, 1990, Pittsburgh, PA
1996	American College of Occupational and Environmental Medicine, Medical Review Officer Refresher Course, October 27, 1996, Toronto, Ontario, Canada

MEDICAL SPECIALTY BOARD CERTIFICATION

1991-present	American Board of Preventive Medicine, Occupational Medicine

LICENSURE

1988-present	Oklahoma 16402
1990-present	Wisconsin 31165
1998-2017	Illinois 0036-098014

PROFESSIONAL EXPERIENCE

1972-1979	Staff Positions, Epidemiology Program, Division of Communicable Disease Control, Oklahoma State Department of Health, Oklahoma City, OK.
1979-1982	State Epidemiologist and Chief of the Epidemiology Service, Oklahoma State Department of Health, Oklahoma City, OK.
1982-1986	Consultant Environmental Epidemiologist, Environmental Health Services, Oklahoma State Department of Health, Oklahoma City, OK.
1987-1990	Medical/Environmental Epidemiologist, Environmental Health Services, Oklahoma State Department of Health, Oklahoma City, OK.
1990-1996	Assistant Professor, Medical College of Wisconsin, Department of Preventive Medicine, Milwaukee, WI.
1991-1997	Medical Director, Employee Health Services, Miller Brewery, Aldrich Chemicals, St. Mary's Hospital, Wisconsin Centrifugal and Wisconsin Bell Milwaukee, WI.
1994-1997	Residency Programs Director, Medical College of Wisconsin, Department of Preventive Medicine, Milwaukee, WI.
1994-1997	Assistant Professor, Medical College of Wisconsin, Health Policy Institute (Epidemiology), Milwaukee, WI.
1995-1997	Acting Chairman, Medical College of Wisconsin, Department of Preventive Medicine, Milwaukee, WI.
1995-1997	Medical Consultant, Rowan & Blewitt, Inc., Washington, DC.
1996-1997	Associate Professor, Medical College of Wisconsin, Department of Preventive Medicine, Milwaukee, WI.
1996-1997	Medical Director, Medical College of Wisconsin, Occupational Health Clinic, Milwaukee, WI.
1996-1997	Medical Advisor to Administrative Law Judge, Social Security Administration, Office of Hearings and Appeals, Milwaukee, WI.
1997-1998	Associate Corporate Medical Director, Amoco Corporation, Chicago, IL.
1998-2000	Associate Corporate Medical Director and Regional Medical Advisor for North America, BP Inc., London, UK.
2000- 2003	Corporate Medical Director and Regional Medical Advisor for North America, BP Inc., London, UK.
2003-2007	Senior Managing Scientist, Exponent, Chicago, IL.
2007-present	Medical Advisor, West Allis Health Department, West Allis, WI.
2007-present	Medical Advisor, Wauwatosa Health Department, Wauwatosa, WI.
2007-present	Principal Scientist, Health Practice, Exponent, Chicago, IL.

PROFESSIONAL EXPERIENCE (continued)

2009-2015	Director, Exponent Center for Occupational and Environmental Health
2010-present	Member, Exponent Institutional Review Board (IRB)
2011-present	Member, Exponent Safety Committee

BOARDS, PANELS, COMMITTEES AND DIRECTORSHIPS

1990- 1995	Health Studies Review Group, Agency for Toxic Substances and Disease Registry, Division of Health Studies, Atlanta, GA.
1991- 1996	Member, Public Health Committee, Medical Society of Milwaukee County, Milwaukee, WI.
1991- 1994	Member, Commission on Environmental and Occupational Health, State Medical Society of Wisconsin, Madison, WI.
1991-1998	Representative of the State Medical Society, Wisconsin Hospital Association's Task Force on Environmental Issues, Madison, WI.
1991-1992	Special Committee on Medical Waste Disposal, Wisconsin Department of Natural Resources, Madison, WI.
1991- 1993	Member of Public Health Advisory Forum, Wisconsin Department of Health and Social Services, Division Health, Madison, WI.
1992-1997	Member, Environmental Medicine Committee, American College of Occupational and Environmental Medicine, Arlington Heights, IL.
1993-1997	Chairman, Committee on Liaison with Governmental Agencies, Council on External Affairs, American College of Occupational and Environmental Medicine, Arlington Heights, IL.
1994-1998	Chairman, Commission on Environmental and Occupational Health, State Medical Society of Wisconsin, Madison, WI.
1994-1998	Member, Great Lake Fish Consumption Advisory Protocol Panel, Michigan Environmental Science Board, Lansing, MI.
1995-1998	Member, Board of Scientific Counselors, Agency for Toxic Substances and Disease Registry, Atlanta, GA.
1995-1996	Member, Institutional Strategic Plan Task Force, Education Task Force for the Medical College of Wisconsin, Milwaukee, WI.
1995-1996	Member, Rehabilitation Center Task Force, Medical College of Wisconsin, Milwaukee, Wisconsin.
2000-2007	Member, Board of Directors, American College of Occupational and Environmental Medicine, Chicago, IL.
2001-2002	Member, Board of Directors, Vysis, Inc, Downers Grove, IL.
2004-2010	Member, Institute of Medicine of Chicago, Chicago, IL
2005-2006	Treasure, Medical Directors Club of Chicago, Chicago, IL
2006-2007	President, Medical Directors Club of Chicago, Chicago, IL
2008-2011	Member, Board of Directors, American College of Occupational and Environmental Medicine, Chicago, IL.
2008-2015	Associate Clinical Professor, Institute of Health and Society, Medical College of Wisconsin, Milwaukee, WI
2010-2016	Board of Directors, Chicago Section of American Industrial Hygiene Association, Chicago, IL

BOARDS, PANELS, COMMITTEES AND DIRECTORSHIPS (continued)

2011-2014	Board of Governors, Central States Occupational & Environmental Health Association, Chicago, IL
2012-2013	Committee on Potential Health Risks from Recurrent Lead Exposure to DOD Firing Range Personnel, National Research Council, National Academies, Washington, DC
2010-2015	Advisory Board member, Illinois Occupational Surveillance Program at the University of Illinois at Chicago, Environmental and Occupational Health Science Division
2010-Present	Residency Advisory Committee, University of Illinois at Chicago, Occupational Medicine Residency Program, Chicago, IL
2013-2014	Vice President, American College of Occupational and Environmental Medicine, Arlington Heights, IL
2015-2016	President, American College of Occupational and Environmental Medicine, Arlington Heights, IL
2016-2017	Past President, American College of Occupational and Environmental Medicine, Arlington Heights, IL
2016-Present	Advisory Board Member, Underwriters Laboratory, Integrated Health and Safety Institute, Northbrook, IL

PUBLICATIONS

Editor, Oklahoma Communicable Disease Bulletin, a weekly publication covering current topics of public health interest. 1977-82.

Saah A., Mallonee J., Tarpay M., Thornsberry C., Roberts M., Rhoades E. "Relative Resistance to Penicillin in Pneumococcus: A Prevalence and Control Study," J. Am. Med. Assoc., Volume 243, Number 18, 1980, pp. 1824-1827.

Bernard K., Roberts M., Sumner J., Winkler G., Mallonee J., Baer G., Chaney R."Human Diploid Cell Rabies Vaccine," J. Am. Med. Assoc., Volume 247, Number 8, 1981, pp. 1138-1142.

Morton D., Saah A., Silberg S., Owens W., Roberts M. "Lead Absorption Among Children of Employees in a Lead Related Industry," Am. J. Epid., Volume 115, Number 4, April 1982, pp.549-555.

Vernon A., Thacker S., Roberts M., Mallonee J., Beauchamp H. "Rabies in Oklahoma: An Epidemiologic View of the Problem in Animals," J. Okla. State Med. Assoc., Volume 76, Number 8, August 1982, pp. 293-299.

Helmick C., Vernon A., Schwartz S., Ward M., Roberts M. "Rabies in Oklahoma: Report of a Human Case," J. Okla. State Medical Assoc., Volume 76, Number 8, August 1982, pp. 287-292.

Tacket C., Barrett T., Mann J., Roberts M., Blake P. "Wound Infection Caused by Vulnificus, A Marine Vibrio, In Inland Areas of the United States," J. Clin. Micro., 1984, Volume 19, pp.97-99.

PUBLICATIONS (continued)

Felsenfeld A, Roberts M. "A Report of Fluorosis in the United States Secondary to Drinking Well Water, "J. Am. Med. Assoc., Volume 265, Number 4, January 1991, pp. 486-488.

Roberts M., O'Brien M. "Public Health and the Environment: Where Do We Go From Here?" Invited Article, Wisconsin Public Health Association Newsletter, Milwaukee, Wisconsin, March 1994.

Clarke C., Mowat F., Kelsh M., Roberts M. "Pleural Plaques: A Review Of Diagnostic Issues And Possible Non-Asbestos Factor," Arch. Env. & Occ. Health, Vol. 61, Number 4, July/August 2006, pg. 183-192.

Alexander D., Cushing C., Lowe K., Sceurman B., Roberts M. "Meta-analysis of animal fat or animal protein intake and colorectal cancer," Am. J. Clin. Nutr. 2009;89:1-8.

Hymel P, Loeppke, R., Baase, C., Burton, W., Hartenbaum, N., Hudson, W., McLellan, R., Mueller, K., Roberts, M., Yarborough, C., Konicki, D., and Larson, P., "Workplace Health Protection and Promotion: A New Pathway for a Healthier and Safer Workforce," J. Occ & Env Health Vol. 53, Number 6, June 2011, pp. 695-702

Roberts, J., Roberts, M., "Wind Turbines: is there a human risk," J. Env. Health, Vol. 75, Number 8, April 8, 2013.

Loeppke, R et al., "Integrating Health and Safety in the Workplace," J. Occ & Env Health Vol. 57, Number 5, May 2015, pp. 685-697

BOOK CHAPTERS

Roberts M., "Role of Aviation in the Transmission of Disease," Fundamentals of Aerospace Medicine, Second Edition, 1996, Chapter 33, pp. 1003-1015.

Hudson, TW, Roberts, M., "Corporate Response to Terrorism," in Clinics in Occupational and Environmental Medicine, "Terrorism: Biological, Chemical and Nuclear, Volume 2, Number 2, February 2003, pages 389-404.

REPORTS/SURVEYS

Roberts, M., Walker F., "Cancer Cluster Investigation in Ponca City Oklahoma," Oklahoma State Department of Health, 1988, Oklahoma City, OK.

Greaves W., Roberts M., Moore S. "Investigation of Employee Health," November 1990, Modine Manufacturing Company, Emporia, KS.

Roberts, M., "Medical Waste Disposal in the State of Wisconsin: A Report of the Special Committee on Medical Waste Disposal, "Report to the Wisconsin Legislature, PUBL-AM-068-91, October 23, 1991, Madison, WI.

Roberts M., "Investigation of Suspected Building Associated Illness in a Public School Building," December 1993, Milwaukee, WI.

Roberts M., Cohen S. "Cancer Mortality Studies of a Petroleum Refinery Employee Cohort," January 1994, Milwaukee, WI.

REPORTS/SURVEYS (continued)

Roberts M., Cohen S. "Utility of Health Surveillance in a Petroleum Refinery Employee Cohort," April 1994, Milwaukee, WI.

Roberts M., Kitscha D & Blessinger J. “Cohort Mortality Study Update of Employees at the Velsicol Chattanooga Plant 1943-1992," Milwaukee, WI.

Fischer L., Bolger P., Calson G., Jacobson J., Knuth B., Radike M., Roberts M., Thomas P., Wallace K., Harrison K. “Critical Review of a Proposed Uniform Great Lakes Fish

Advisory Protocol,” September, 1995. Michigan Environmental Science Board, Lansing, MI.

Roberts M., Kitscha D. “Evaluation of Respiratory Complaints Associated with Metal Milling Processes,” Milwaukee, WI. August 1996

Roberts M., Kitscha D. "Evaluation of Indoor Air Quality in a Public School Setting: A Case Control Study," Kenosha, WI. October 1996

Roberts, M. “Evaluation of the Scientific Literature on the Health Effects Associated with Wind Turbines and Low Frequency Sound”, prepare for Wisconsin Electrical Power Company (WEPCO), October 29, 2009, Milwaukee, WI.

COURSE STUDY GUIDES
For Distance Learning Program

Roberts, M., "Environmental Health: A Study Guide," Academic Program in Occupational Medicine, Medical College of Wisconsin, August 1992, Milwaukee, WI.

Roberts, M., O'Brien, M. "Biostatistics: A Study Guide," Academic Program in Occupational Medicine, Medical College of Wisconsin, April 1994, Milwaukee, WI.

PRESENTATIONS

"Preliminary Report on a Statewide Rabies Pre-exposure Prophylaxis Program,” The International Northwestern Conference on Diseases in Nature Communicable to Man, August 12-14, 1974, Boise, ID.

"Geographical and Ecological Distribution of Rocky Mountain Spotted Fever in Oklahoma," Twenty-seventh Annual Southwest Conference on Diseases in Nature Transmissible to Man, March 10-11, 1977, Austin, TX.

"Foodborne Illness Incidence and Investigation," National Society of Professional Sanitarians' Annual Meeting, November 1-3, 1979, Springfield, MO.

"A Serosurvey of Brucella canis Antibody Titers in Dogs and Their Owners," Thirtieth Annual Southwest Conference on Diseases in Nature Transmissible to Man, March 27-28, 1980, Temple, TX.

"A Human Rabies Case in Oklahoma," Thirty-second Annual Southwest Conference on Diseases in Nature Transmissible to Man, March 25-26, 1982, Austin, TX.

"On the Other Side of the Fence," Seventy-fourth meeting, American Occupational Health Conference, April 29-May 5, 1989, Boston, MA.

PRESENTATIONS (continued)

"Indoor Air Pollution - Update," University of Tulsa Division of Continuing Education and the Center for Environmental Research and Technology, May 8-9, 1989, Oklahoma City, OK.

“Issues and Decisions in Environmental Health," University of Oklahoma Academy of Retired Professors, Sept 26, 1989, Norman, OK.

"Balancing Public Health and Environmental Health," Oklahoma Society of Professional Sanitarians. October 12, 1989, Oklahoma City, OK.

“Occupational Health and Epidemiology," University of Oklahoma, College of Public Health, Alumni Day 1989, Oklahoma City, OK.

"Environmental Aspects of Economic Development: Realities vs. Perceptions," Leadership Oklahoma 1990, March 2, 1990, Ponca City, OK.

"Occupational Health Team Members and Resources," Practical Approaches to Occupational Medicine, March 3, 1990, Oklahoma City, OK.

"Putting Environmental Health Back in Public Health," South Carolina Public Health Association Annual Meeting, May 24, 1990. Myrtle Beach, S.C.

"Board Certification in Occupational Medicine," Industrial Epidemiology Forum, May 1990, Salt Lake City, UT.

"Environmental Epidemiology in Relation to Occupational Medicine," Midwestern Medical Director's Association (Insurance Medicine), October 26, 1990, Wausau, WI.

"Environmental Medicine: Fact or Fantasy," Oklahoma College of Occupational Medicine, Fifteenth Annual Fall Educational Meeting, November 2-3, 1990, Edmond, OK.

"Drug Testing in the Workplace," 21st Annual Winter Refresher Course for Family Physicians, January 21, 1991, Milwaukee, WI.

"Risk Communication: Challenge of Today's Society," Oklahoma Public Health Association Annual Meeting, April 4, 1991, Tulsa, OK.

"Social, Political and Legal Aspects of Environmental Health," American College of Occupational Medicine, State of the Art Conference, Seminar Director, October 28, 1991, St. Louis, MO.

"Workplace Standards Applied to the Non-Workplace Population," American College of Occupational Medicine, State of the Art Conference, October 31, 1991, St. Louis, MO.

"Strategic Planning for the Americans with Disabilities Act," Hospital Council of Greater Milwaukee Area, Co-Director, March 31, 1992., Milwaukee, WI.

"Health and Safety in the Health Care Workplace," Krukowski & Costello, S.C., Guest Speaker, June 6, 1992, Oconomowoc, WI.

"Trials and Tribulations of Occupational Medicine in Primary Care," Family Health Plan's Eight Annual Family Practice Symposium, Invited Speaker, August 5, 1992, Milwaukee, WI.

PRESENTATIONS (continued)

"Business Partnership Opportunities in Occupational and Environmental Medicine," Discussion Leader, Governor's Forum on Technological Transfer and Business Partnerships, September 24, 1992, Milwaukee, WI.

"Effects of the Americans with Disability Act on Industry," Wisconsin State Association of Occupational Health Nurses, 6th Annual Meeting, Invited Speaker, October 8, 1992, LaCrosse, WI.

"Community TB Control: The Good, the Bad and the Ugly," American Lung Associations' conference "TB in the '90s: An Aberration or an Epidemic?", Invited Speaker, October 16, 1992, Madison, WI.

"Occupational Medicine in the Hospital Setting," Medical Grand Rounds Williamsport Hospital & Medical Center, Invited Speaker, April 16, 1993, Williamsport PA.

"Sick Building Syndrome: Fact or Fantasy?" Milwaukee Area Medical Directors' Association, January 23, 1994, Milwaukee, WI.

"Biological Monitoring from the Industrial Viewpoint," American Occupational Health Conference, April 15-22, 1994, Chicago, IL.

"Biological Monitoring," Session Moderator, American Occupational Health Conference, April 15-22, 1994, Chicago, IL.

"Occupational Health: Resolve to Reform," Keynote Address, Southeastern Wisconsin Association of Occupational Nurses Annual Meeting, May 11, 1994, Milwaukee, WI.

"ADA Issues in the Hospital Setting," St. Mary's Hospital Administrative Staff, January 11, 1995, Milwaukee, WI.

"Update on the Clinical and Epidemiological Aspects of Indoor Air Complaints," Indoor Air Quality Seminar, January 19, 1995, Madison, WI.

"Plugging Occupational and Environmental Concepts into Medical Schools," ACOEM Session #137, "Integrating Environmental Health into Medical School Curricula," April 28-May 5, 1995, Las Vegas, NV.

"Bloodborne Pathogens: The Standard and Its Implementation," Milwaukee Area Medical Directors' Association, May 18, 1995, Milwaukee, WI.

"The Clinical Importance of Sick Building Syndrome," University of Oklahoma College of Medicine, Department of Family Medicine, Grand Rounds, August 24, 1995, Oklahoma City, OK.

"Psychological Factors in Occupational Medicine and Rehabilitation," Milwaukee Psychiatric Hospital, Invited Speaker, Contemporary Issues in Mental Health and Addiction Medicine, September 6, 1995, Milwaukee, WI.

"Multiple Chemical Sensitivity," Wisconsin State Association of Occupational Health Nurses, 8th Annual Meeting, Invited Speaker, October 4, 1995, Egg Harbor, WI.

"Health Problems Associated with Pesticide Contaminated Well Water" Conference on Common Rural and Agricultural Health Problems, sponsored by the Marshfield Clinic, May 9, 1996 Madison, WI.

PRESENTATIONS (continued)

“Indoor Air Complaint Evaluations: An Update”, Central States Occupational Medicine Association, September 28, 1996, Milwaukee, WI.

“Summer and Vacation Safety,” Milwaukee Area Safety Council, May 2, 1997, Milwaukee, WI.

“Basic Safety & Health for Occupational Health Practitioners,” Veterans Affairs Medical Center, September 12, 1997, Little Rock, AR.

“Epidemiological Issues in Welding Fume Exposure.” Harris Martin Welding Rods Conference, June 16th, 2004, San Francisco, CA.

“Silica: Complex Made Simple,” Ohio Association of Civil Trial Attorneys Asbestos & Silica Litigation Conference, September 29, 2004, Cleveland, OH.

“Diagnosing and Proving Manganese Exposure.” Mealey’s Welding Rod Litigation Conference, October 8, 2004, West Palm Beach, Florida.

“Epidemiological Issues in Welding Fume Exposure.” Mealey’s Welding Rod Litigation Conference, November 15, 2004, New Orleans, LA.

“Welding Rod Litigation: A Primer on the Legal and Medical/Science Issues,” DRI Telephone Conference, March 8th, 2005, Chicago, IL.

“Diagnosing and Proving Manganese Exposure.” ACI Second National Forum on Welding Rod Litigation, June 20, 2005, Chicago, IL.

“What’s the Next Deep Pocket Mass Tort to Hit the Automotive Industry?” Product Liability-Hot Topics Seminar for Defense Counsel, September 14, 2005, Troy, MI.

“Emerging Health Issues in Welding.” Chicago Section AIHA and Northeastern IL Chapter of ASSE, November 16, 2005, Palatine, IL.

“Rules of the Communication Road.” AIHce 2007 Roundtable “Communicating Risk / Communicating Cause,” June 6, 2007, Philadelphia, PA.

“Integration of Health and Productivity Programs with Safety Performance” CICI Conference, November 27, 2007, Willowbrook, IL.

“Advanced Epidemiology: The Good, The Bad and The Ugly,” DRI Complex Medicine Seminar, November 13, 2008, San Diego, CA.

“Careers in Occupational and Environmental Health: Public Health, Corporate Practice, Academia or Consulting?” UIC Occupational and Environmental Medicine Conference, March 4, 2009, Chicago, IL.

“Occupational and Environmental Health: Challenges in Public Health, Corporate Practice, Academia and Consulting?” UIC Occupational and Environmental Medicine Conference, August 18, 2010, Chicago, IL.

“What’s New is Old: Emerging Health Issues from Alternative Energy” Exponent Webinar, Chicago, IL, March 30, 2012

“Introduction to Industrial Hygiene,” ACOEM Foundations Course, Los Angeles, CA, April 27-28, 2012

PRESENTATIONS (continued)

"Environmental Impacts of Alternative Energy Technologies: Fatal Flaws and Why Some Projects Fail," Exponent Webinar, Chicago, IL November 26, 2012

"Weighty Issues in the Workplace" Central States Occupational & Environmental Medicine, Spring 2013 Meeting, March 15, 2013, Lisle, IL.

"Weighty Issues in the Workplace" WorkSafe Iowa Spring 2013 Network Meeting Heartland Center for Occupational Health and Safety, University of Iowa College of Public Health, Cedar Rapids, IA May 2, 2013

"Natural gas extraction -Rising energy demands mandate a multi-perspective approach" AIHA 2013 Fall Conference Workshop, Miami, FL October 1, 2013

"Epidemiology 101: A real World adaptation" University of Illinois, Chicago, IL January 12, 2015.

"Waterborne Diseases" Professional Development Course, Chicago Section AIHA, West Chicago, IL, April 21, 2015

"Navigating Wind Energy Issues" Webinar, Chicago, IL April 29, 2015

"Biofilms in Drinking Water: Creative Creatures" Society of Occupational Medicine Annual Scientific Meeting, Manchester, England, July 9, 2015

"Evolving Science: Danger Work Ahead," Michigan Occupational & Environmental Medicine Association's 90th Annual Scientific Meeting, Lansing, MI, September 19, 2015

"The Good, The Bad, and The Ugly of Evidence & Risk based Health Surveillance," Employee Health & Wellbeing Conference, Doha, Qatar, October 11-13, 2015

"Hot Topics in OSHA Compliance" Webinar, Chicago, IL November 10, 2015

ACOEM Presidential presentations in 2016 included numerous presentations to Components, other health and safety organizations and international groups.

POSTER SESSIONS

Roberts M. "TOMES/CCIS Computerized Information Systems," Health Information Technology Symposium, Medical College of Wisconsin, November 8, 1990, Milwaukee, WI.

Roberts M., Lindemann J, Simpson D., and Tyborski M. "Computerization of the Educator's Portfolio," Central Group on Educational Affairs, Innovations in Medical Education, Central Region Research in Medical Education, April 22, 1994, Chicago, IL.

POSTER SESSIONS (continued)

Roberts M.M., Parks TJ, Wertsch JJ, and Roberts M.A., “Ulnar Sensory Responses in the Elderly”, American Academy of Electromyography, Annual Scientific Meeting, September 30-October 1, 1994, San Francisco, CA.

Roberts M.M., Parks TJ, Wertsch JJ, Roberts M.A. “Median, Ulnar, and Radial Sensory Responses in the Elderly,” American Academy of Electromyography, Annual Scientific Meeting, September 30-October 1, 1994, San Francisco, CA.

Roberts M., Lindemann J, Simpson D, and Tyborski M “Results of Beta Testing of the Computerized Version of the Educator’s Portfolio, 33rd Annual Research in Medical Education Conference, Association of American Medical Colleges, October 30-November 1, 1994, Boston, Massachusetts.

Lindeman J., Roberts M., Simpson D. The Educator’s Portfolio: Beta testing of the Computerized Version, Electronic Poster Session, 28th Annual STFM Spring Conference, New Orleans, 1995.

ABSTRACTS

Hegmann KT, Greaves W., Moore SJ, Roberts M. "Case-Control Study of Respiratory and Reproductive Symptoms at an Automobile Parts Manufacturing Facility." Accepted for Society for Epidemiological Research, June 15-18, 1994, Miami Beach, FL.

Alexander D., Cushing C., Roberts M. Quantitative assessment of red and processed meat intake and kidney cancer. Experimental Biology, New Orleans, LA 2009.

EDUCATIONAL ACTIVITIES

Undergraduate

1992-97	Lecturer, M-3 Ambulatory Medicine Course, Topic “Low Back and Shoulder Examination”
1992-97	Lecturer, M-1 Gross Anatomy, Topic “Plug in Concepts related to Low Back Pain,” includes a series of 4 team-taught lectures.
1994-97	Senior Elective Preceptor & M-1 Mentor Program, Occupational & Environmental Medicine Medical College of Wisconsin.

Graduate

1992-98	MPH Student Project Advisor, Distance Learning Program at Medical College of Wisconsin
1992-98	Epidemiology Course Coordinator and Primary Instructor, Master’s Degree in Public Health, Medical College of Wisconsin, Department of Preventive Medicine, Milwaukee, Wisconsin (Ave 49 students per trimester.)
1992-98	Environmental Health Course Coordinator and Primary Instructor, Masters Degree in Public Health, Medical College of Wisconsin, Department of Preventive Medicine, Milwaukee, Wisconsin (Ave 36 students per trimester).
1992-1994	Biostatistics Course Coordinator and Primary Instructor, Master’s Degree in Public Health, Medical College of Wisconsin, Department of Preventive Medicine, Milwaukee, Wisconsin (Ave 34 students per trimester).

EDUCATIONAL ACTIVITIES (continued)

1992-97 Waukesha Memorial Hospital Family Medicine Residency Program, Resident supervisor for rotations in Occupational Medicine.

1993-97 Columbia Family Practice Residency Program, Resident supervisor for rotations in Occupational Medicine.

1995 Course Director and lecturer, Basic Curriculum in Occupational Medicine Part II presented to physicians attending the American College of Occupational and Environmental Medicine Meeting, October 21-22, 1995 Seattle, Washington.

1995-99 Lecturer, Basic Curriculum in Occupational Medicine Part II presented to physicians attending the American College of Occupational and Environmental Medicine Meetings

CME Courses

Video Production- "Musculoskeletal Workshop Low Back/Shoulder Exam," a one hour presentation distributed by the Division of Educational Services, Medical College of Wisconsin, 1994.

Employee Health Services in the Hospital Setting, American Practitioners of Infection Control and Epidemiology, St. Michael's Hospital, October 6, 1994.

Educational Software Development

Educator's Portfolio --Directed the development of a computer software package to track educational activities of faculty members

Professional Courses and Educational Programs

2000-present Various positions on the American College of Occupational & Environmental Medicine, Council of Education.

2011-2014 Course Co-Chairman, American College of Occupational & Environmental Medicine, Foundation Courses in Occupational & Environmental Medicine.

2012-Present Lecturer and Coordinator, Introduction to Occupational Medicine, presented yearly at the American Occupational Health Conference

2013 Program Co-Chairman, Spring Meeting of Central States Occupational & Environmental Medicine, Lisle, IL.

OTHER EDUCATIONAL ACTIVITIES

Community Service Media Relations

1994-97 Seminars and Presentations related to Media Interaction
"Working with the Media," Medical College of Wisconsin Symposium, Milwaukee, Wisconsin, September 20, 1995.

National Television

Public Broadcast System (PBS) Series "The World Can Make You Sick," Milwaukee, Wisconsin, November 19, 1993.

CNN News "A Health and Safe Thanksgiving," a five part series on preparation for Thanksgiving produced here in Milwaukee and aired on nationally on CNN November 28, 1996.

National Television (continued)

TiP-TV “Keys to Good Health: Wellness Programs & Preventive Medicine,” June 6, 1997, 2:00-3:30 CTD, General Electric Company, 900 sites worldwide and approximately 15,000 participants.

Educational Outreach Video Conference, Managing Your Health & Health Care Program, “Maintaining a Healthy Lifestyle,” a 2 ½ hour broadcast presentation, Brookfield, Wisconsin, November 21, 1996.

Moderator, Spring Educational Outreach Program, Children’s’ Health and Parenting, “Perinatal to Newborn,” a 2 ½ hour broadcast presentation, Brookfield, Wisconsin, April 3, 1997.

Moderator, Spring Educational Outreach Program, Children’s’ Health and Parenting, “Elementary School Ages,” a 2 ½ hour broadcast presentation, Brookfield, Wisconsin, April 17, 1997.

Local Television

1994-97 Wrote and Co-produce twice weekly segments addressing public health and clinical issues for WITI Channel 6 TV viewing audience estimated at 37,000 in greater Milwaukee area.

Radio (Commercial and Public Stations)

1992-97 Frequent contributor to news stories covering issues related to Preventive Medicine and Public Health for the Milwaukee radio market.

WTMJ-AM 620 Noon Show “Industrial, Environmental, and Occupational Medicine,” July 18, 1994.

PBS Kathleen Dunn, Kathleen Dunn Show, WHAD-FM Wisconsin Public Radio discussing “Ebola Virus in Africa.”

2015 WGN Program, “Legal Face-off” with Jason Whiteside and Rich Lenkov discussing “Health Issues in the News,” March 15, 2015.

PROFESSIONAL SOCIETIES

American College of Occupational and Environmental Medicine
Central States Occupational and Environmental Medical Association
Chicago Area Medical Directors Association
American Industrial Hygiene Association
American Conference of Governmental Industrial Hygienists

REFERENCES UPON REQUEST

Australian Government

National Health and
Medical Research Council

NHMRC

Wind Turbines and Health

A Rapid Review of the Evidence

July 2010

Wind Turbines and Health – A Rapid Review of the Evidence

The purpose of this paper is to present findings from a rapid review of the evidence from current literature on the issue of wind turbines and potential impacts on human health. In particular the paper seeks to ascertain if the following statement can be supported by the evidence: *There are no direct pathological effects from wind farms and that any potential impact on humans can be minimised by following existing planning guidelines.* This statement is supported by the 2009 expert review commissioned by the American and Canadian Wind Energy Associations (Colby et al. 2009).

Context

In Australia, since the legislation of the *Renewable Energy (Electricity) Act* in 2000, wind power has been gaining prominence as a viable sustainable alternative to more traditional forms of energy production. Studies have found that there is increasing population demand for 'green' energy and that people are willing to pay a premium for renewable energy (Chatham-Kent Public Health Unit, 2008; Pedersen & Persson Waye, 2007). However as with any shift in technology, the emergence of wind farms is not without controversy.

There are two opposing viewpoints regarding wind turbines and their potential effect on human health. It is important to note that these views are frequently presented by groups or people with vested interests. For example, wind energy associations purport that there is no evidence linking wind turbines to human health concerns. Conversely, individuals or groups who oppose the development of wind farms contend that wind turbines can adversely impact the health of individuals living in proximity to wind farms.

Concerns regarding the adverse health impacts of wind turbines focus on the effects of infrasound, noise, electromagnetic interference, shadow flicker and blade glint produced by wind turbines. Does the evidence support these concerns?

Sound and Noise from Wind Turbines

Sound is composed of frequency expressed as hertz (Hz) and pressure expressed as decibels (dB). In terms of frequency sound can be categorised as audible and inaudible. Infrasound is commonly defined as sound which is inaudible to the human ear (below 16 Hz). Despite this commonly used definition, infrasound can be audible (EPHC, 2009). There is often confusion regarding the boundary between infrasound and low frequency noise (Leventhall, 2006). Human sensitivity to sound, especially to low frequency sound, is variable and people will exhibit variable levels of tolerance to different frequencies (Minnesota Department of Health, 2009).

Noise can be defined as any undesirable or unwanted sound. The perception of the noise is also influenced by the attitude of the hearer towards the sound source. This is sometimes called the nocebo effect, which is the opposite of the better known placebo effect. If people have been preconditioned to hold negative opinions about a noise source, they are more likely to be affected by it (AusWEA, 2004).

Wind turbines produce noise that can be classified into the following categories:

1. Mechanical noise which is produced from the motor or gearbox; if functioning correctly, mechanical noise from modern wind turbines should not be an issue.
2. Aerodynamic noise which is produced by wind passing over the blade of the wind turbine (Minnesota Department of Health, 2009).

As well as the general audible range of sound emissions, wind turbines also produce noise that includes a range of Special Audible Characteristics (SACs) such as amplitude modulation, impulsivity, low frequency noise and tonality (EPHC, 2009).

Table 1 compares the noise produced by a ten turbine wind farm compared to noise levels from some selected activities.

Activity	**Sound pressure level (dBA)**[1]
Jet aircraft at 250m	105
Noise in a busy office	60
Car travelling at 64kph at 100m	55
Wind farm (10 turbines) at 350m	**35-45**
Quiet bedroom	35
Background noise in rural area at night	20-40

Table 1: Noise levels compared to ten turbine wind farm (SDC, 2005).

Macintosh and Downie (2006) conclude that based on these figures "noise pollution generated by wind turbines is negligible".

One of the most common assertions regarding potential adverse noise impacts of wind turbines is concerned with low frequency noise and infrasound. It should be noted that infrasound is constantly present in the environment and is caused by various sources such as ambient air turbulence, ventilation units, ocean waves, distant explosions, volcanic eruptions, traffic, aircraft and other machinery (Rogers, Manwell & Wright, 2006). In relation to wind turbines, Leventhall (2006) concludes that there is insignificant infrasound generated by wind turbines and that there is normally little low frequency noise. A survey of all known published results of infrasound from wind turbines found that wind turbines of contemporary design, where rotor blades are in front of the tower, produce very low levels of infrasound (Jakobsen, 2005). Another recent report concludes that wind farm noise does not have significant low-frequency or infrasound components (Ministry of the Environment, 2007). As discussed in further detail below the principal human response to audible infrasound is annoyance (Rogers, 2006).

Effects of Noise from Wind Turbines on Human Health

The health and well-being effects of noise on people can be classified into three broad categories:

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[1] The "A" represents a weighting of measured sound to mimic that discernable by the human ear, which does not perceive sound at low and high frequencies to be as loud as mid range frequencies (AusWEA, nd. a).

1. subjective effects including annoyance, nuisance and dissatisfaction;
2. interference with activities such as speech, sleep and learning; and
3. physiological effects such as anxiety, tinnitus or hearing loss (Rogers, Manwell & Wright, 2006).

Several commentators argue that noise from wind turbines only produces effects in the first two categories (Rogers, 2006; Pedersen & Persson Waye, 2007).

Various studies of wind turbine effects on health have concentrated on the self-reported perception of annoyance. There are difficulties with measuring and quantifying subjective effects of noise such as annoyance. According to the World Health Organization (WHO) (1999) annoyance is an adverse health effect, though this is not universally accepted. Kalveram proposes that annoyance is not a direct health effect but an indication that a person's capacity to cope is under threat. The person has to resolve the threat or their coping capacity is undermined, leading to stress related health effects (Kalveram 2000). Some people are very annoyed at quite low levels of noise, whilst other are not annoyed by high levels.

It has been suggested that if people are worried about their health they may become anxious, causing stress related illnesses. These are genuine health effects arising from their worry, which arises from the wind turbine, even though the turbine may not objectively be a risk to health (Chapman 2010). The measurement of health effects attributable to wind turbines is therefore very complex.

One study of wind turbine noise and annoyance found that no adverse health effects other than annoyance could be directly correlated with noise from wind turbines. The authors concluded that reported sleep difficulties, as well as feelings of uneasiness, associated with noise annoyance could be an effect of the exposure to noise, although it could just as well be that respondents with sleeping difficulties more easily appraised the noise as annoying (Pedersen & Persson Waye, 2007).

Many factors can influence the way noise from wind turbines is perceived. The aforementioned study also found that being able to see wind turbines from one's residence increased not just the odds of perceiving the sound, but also the odds of being annoyed, suggesting a multimodal effect of the audible and visual exposure from the same source leading to an enhancement of the negative appraisal of the noise by the visual stimuli (Pedersen & Persson Waye, 2007). Another study of residents living in the vicinity of wind farms in the Netherlands found that annoyance was strongly correlated with a negative attitude toward the visual impact of wind turbines on the landscape. The study also concluded that people who benefit economically from wind turbines were less likely to report noise annoyance, despite exposure to similar sound levels as those people who were not economically benefiting (Pedersen et al, 2009).

In addition to audible noise, concerns have been raised about infrasound from wind farms and health effects. It has been noted that the effects of low frequency infrasound (less than 20Hz) on humans are not well understood (NRC, 2007). However, as discussed above, several authors have suggested that low level frequency noise or infrasound emitted by wind turbines is minimal and of no consequence (Leventhall, 2006; Jakobsen, 2005). Further, numerous reports have concluded that there is no evidence of health effects arising from infrasound or low frequency noise generated by wind turbines (DTI, 2006; CanWEA, 2009; Chatham-Kent Public Health Unit, 2008; WHO, 2004; EPHC, 2009; HGC Engineering, 2007). In summary:

- ‘There is no reliable evidence that infrasounds below the hearing threshold produce physiological or psychological effects’ (Berglund & Lindvall 1995).

- Infrasound associated with modern wind turbines is not a source which will result in noise levels which may be injurious to the health of a wind farm neighbour (DTI, 2006).

- Findings clearly show that there is no peer-reviewed scientific evidence indicating that wind turbines have an adverse impact on human health (CanWEA, 2009).

- Sound from wind turbines does not pose a risk of hearing loss or any other adverse health effects in humans. Subaudible, low frequency sounds and infrasound from wind turbines do not present a risk to human health (Colby, et al 2009).

- The Chatham-Kent Public Health Unit (Ontario, Canada) reviewed the current literature regarding the known health impacts of wind turbines in order to make an evidence-based decision. Their report concluded that current evidence failed to demonstrate a health concern associated with wind turbines. ‘In summary, as long as the Ministry of Environment Guidelines for location criteria of wind farms are followed … there will be negligible adverse health impacts on Chatham-Kent citizens. Although opposition to wind farms on aesthetic grounds is a legitimate point of view, opposition to wind farms on the basis of potential adverse health consequences is not justified by the evidence’ (Chatham-Kent Public Health Unit, 2008).

- Wind energy is associated with fewer health effects than other forms of traditional energy generation and in fact will have positive health benefits (WHO, 2004).

- ‘There are, at present, very few published and scientifically-validated cases of an SACs of wind farm noise emission being problematic … the extent of reliable published material does not, at this stage, warrant inclusion of SACs … into the noise impact assessment planning stage (EPHC, 2009).

- While a great deal of discussion about infrasound in connection with wind turbine generators exists in the media there is no verifiable evidence for infrasound and production by modern turbines (HGC Engineering, 2007).

The opposing view is that noise from wind turbines produces a cluster of symptoms which has been termed Wind Turbine Syndrome (WTS). The main proponent of WTS is a US based paediatrician, Dr Pierpont, who has released a book ‘Wind Turbine Syndrome: A report on a Natural Experiment, presents case studies explaining WTS symptoms in relation to infrasound and low frequency noise. Dr Pierpont’s assertions are yet to be published in a peer-reviewed journal, and have been heavily criticised by acoustic specialists. Based on current evidence, it can be concluded that wind turbines do not pose a threat to health if planning guidelines are followed.

Shadow Flicker and Blade Glint

Shadow flicker occurs when the sun is located behind a wind turbine casting a shadow that appears to flick on and off as the wind turbine blades rotate (Chatham-Kent Public health Unit, 2008). It is possible to use modelling software to model shadow flicker before the finalisation of a wind farm layout and siting.

Blade glint occurs when the surface of wind turbine blades reflect the sun's light and has the potential to annoy people (EPHC, 2009).

Effects of Shadow Flicker and Blade Glint on Human Health

Shadow flicker from wind turbines that interrupts sunlight at flash frequencies greater than 3Hz has the potential to provoke photosensitive seizures (Harding, Harding & Wilkins, 2008). As such it is recommended that to circumvent potential health effects of shadow flicker wind turbines should only be installed if flicker frequency remains below 2.5 Hz under all conditions (Harding, Harding & Wilkins, 2008).

According to the EPHC (2009) there is negligible risk of seizures being caused by modern wind turbines for the following reasons:

- less than 0.5% of the population are subject to epilepsy at any one time, and of these, approximately 5% are susceptible to strobing light;
- Most commonly (96% of the time), those that are susceptible to strobe lighting are affected by frequencies in excess of 8 Hz and the remainder are affected by frequencies in excess of 2.5 Hz. Conventional horizontal axis wind turbines cause shadow flicker at frequencies of around 1 Hz or less;
- alignment of three or more conventional horizontal axis wind turbines could cause shadow flicker frequencies in excess of 2.5 Hz; however, this would require a particularly unlikely turbine configuration.

In summary, the evidence on shadow flicker does not support a health concern (Chatham-Kent Public Health Unit, 2008) as the chance of conventional horizontal axis wind turbines causing an epileptic seizure for an individual experiencing shadow flicker is less than 1 in 10 million (EPHC, 2009). As with noise, the main impact associated with shadow flicker from wind turbines is annoyance.

In regards to blade glint, manufacturers of all major wind turbine blades coat their blades with a low reflectivity treatment which prevents reflective glint from the surface of the blade. According to the Environment Protection and Heritage Council (EPHC) the risk of blade glint from modern wind turbines is considered to be very low (EPHC, 2009).

Electromagnetic Radiation and Interference

Electromagnetic radiation (EMR) is a wavelike pattern of electric and magnetic energy moving together. Types of EMR include X-rays, ultraviolet, visible light, infrared and radio waves (AusWEA, nd. b).

Electromagnetic interference (EMI) from wind turbines may affect electromagnetic or radiocommunication signals including broadcast radio and television, mobile phones and radar (EPHC, 2009).

As high and exposed sites are best from a wind resource perspective, it is not unusual for any of a range of telecommunications installations, radio and television masts, mobile phone base stations or emergency service radio masts to be located nearby. Care must be taken to ensure that wind turbines do not passively interfere with these facilities by directly obstructing, reflecting or refracting their radio frequency EMR signals.

Effects of Electromagnetic Radiation and Interference from Wind Turbines on Human Health

Electromagnetic Fields (EMF) emanate from any wire carrying electricity and Australians are routinely exposed to these fields in their everyday lives. The electromagnetic fields produced by the generation and export of electricity from a wind farm do not pose a threat to public health (Windrush Energy 2004). The closeness of the electrical cables between wind turbine generators to each other, and shielding with metal armour effectively eliminate any EMF (AusWEA, nd. b).

Measures to Mitigate Potential Impacts of Wind Turbines

As with the introduction of any new technology, some communities are against wind farms being located in their area. Some factors which may increase community concern include coerced or unequal exposure, industrial, exotic and/or memorable nature of the turbine, dreaded, unknown or catastrophic consequences, substantial media attention, potential for collective action and a process which is unresponsive to the community. Voluntary exposure, for example choosing to house the turbine on community land, reduces concern (Adapted by Professor Chapman from Covello et al. methodology 1986).

One review of wind turbines and noise recommends that best practice guidelines such as those identifying potential receptors of turbine noise, following established setbacks and dispelling rumours regarding infrasound which have not been supported by research, are followed in order to mitigate any potential noise issues associated with wind turbines (Howe, 2007).

Sustainable Energy Authority Victoria (2003) also recommend that complying with standards relating to turbine design and manufacturing, site evaluation and final siting of wind turbines will minimise any potential impacts on the surrounding area.

The recently released Draft National Wind Farm Development Guidelines (EPHC, 2009) include detailed methodologies at different stages of the planning and development process to assess such issues as noise and shadow flicker to mitigate any potential impact. Such processes include a range of measures such as high-level risk assessment, data collection, impact assessment, detailed technical studies and public consultation.

Therefore 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.

Conclusion

The health effects of many forms of renewable energy generation, such as wind farms, have not been assessed to the same extent as those from traditional sources. However, renewable energy generation is associated with few adverse health effects compared with the well documented health burdens of polluting forms of electricity generation (Markandya & Wilkinson, 2007).

This review of the available evidence, including journal articles, surveys, literature reviews and government reports, supports the statement that: *There are no direct pathological effects from wind farms and that any potential impact on humans can be minimised by following existing planning guidelines.*

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Review of additional evidence for NHMRC Information Paper: Evidence on Wind Farms and Human Health

FINAL REPORT

Prepared for NHMRC by
Australasian Cochrane Centre (ACC) and
Monash Centre for Occupational and Environmental Health (MonCOEH)

December 2014

Contents

Authors and contributors

The following staff of the Monash Centre for Occupational and Environmental Health and Australasian Cochrane Centre were involved in planning and conducting the review, and contributed to the preparation of the report.

Coordinating Team

Name	*Position*	Contribution
Malcolm Sim	*Professor*	Project co-lead, study selection, data extraction and appraisal, critical interpretation of data, preparation of summary tables, drafting report
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Geza Benke	*Senior Research Fellow*	Study selection, data extraction and appraisal, critical interpretation of data, preparation of summary tables, input to report
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Declarations of Interest

All authors declare they have no financial, personal or professional interests that could be construed to have influenced the conduct or reporting of this review of additional evidence.

Background

Independent Systematic Review

In August 2012, the National Health and Medical Research Council (NHMRC) commissioned an independent reviewer to undertake a comprehensive review of existing scientific literature on the possible effects of wind farms on human health ('the Independent Review'). This review considered a wide range of evidence, comprising both peer reviewed and non-peer reviewed literature. The Independent Review was supplemented by a call (in September 2012) for submissions of evidence for consideration in the systematic review.

The purpose of the systematic literature review was to determine whether there was evidence to establish that emissions from wind farms cause human health effects (Direct Evidence). A background literature review was also conducted to investigate the physiological mechanisms by which the emissions of wind farms could produce adverse health effects (Mechanistic Evidence) and whether health effects had been observed from similar emissions in other exposure settings (Parallel Evidence).

A comprehensive search of the available scientific literature was conducted by the reviewer in October 2012. While 2848 papers were identified in the literature search for the systematic review component of the Independent Review, and an additional 506 references were submitted to NHMRC for consideration, only 161 papers were found to be relevant to the topic and were considered by the reviewers in detail. Of these, only 11 publications (describing seven studies) met the inclusion criteria to address the systematic review questions.

The reviewer assessed the design, quality, relevance and strength of each study included in the systematic review. The overall body of evidence was then analysed for its quality and consistency. The process and findings of the Independent Review were summarised in a report, *Systematic review of the human health effects of wind farms* (the Independent Review report), which was finalised in late 2013[1].

NHMRC Information Paper

The Wind Farms and Human Health Reference Group ('the Reference Group') was established by NHMRC in early 2012 to oversee the systematic review of the literature. The Reference Group comprises experts in public and environmental health, epidemiology and research methodology, acoustics, psychology and sleep, and also includes a consumer advocate.

Under its terms of reference, the Reference Group was also asked to consider the outcomes of the review to inform any update of NHMRC's 2010 Public Statement: *Wind Turbines and Health*, and to identify gaps in the current evidence base that may warrant further research. In response to this task, the Reference Group guided the development of a new draft Information Paper: *Evidence on Wind Farms and Human Health*, with the assistance of a Technical Writer. The draft Information Paper provided the Australian community with a summary of the available evidence on the potential human health effects of wind farm emissions of noise, shadow flicker and electromagnetic radiation (EMR), based on the comprehensive review of the scientific literature. It also explained the process by which the evidence was identified and critically appraised in the Independent Review, and included an explanation of the evidence by the Reference Group together with their recommendations for further research to address gaps in the available evidence.

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[1] Available on the NHMRC website at http://www.nhmrc.gov.au/guidelines/publications/eh54.

Context for this review of additional evidence

The Council of NHMRC considered the draft Information Paper in late 2013 and recommended to the Chief Executive Officer (CEO) that the draft paper be released for public consultation.

On 24 February 2014 the CEO released the draft Information Paper for public consultation, for a period of 45 days[2]. At that time, the Independent Review report was also released by the CEO as background, to assist interested parties in considering the draft Information Paper.

We were contracted to repeat the literature search carried out for the Independent Review, to capture any additional evidence published since October 2012 that addressed the systematic review questions in the final Independent Review report. In consultation with the Office of NHMRC (ONHMRC) and the Reference Group, we assessed whether the additional literature identified in this search met the specific inclusion criteria for the systematic component of the Independent Review.

In addition, we were provided with a list of additional evidence submitted during the public consultation from 24 February to 11 April 2014, and assessed whether this submitted literature met the specific inclusion criteria for the systematic (Direct Evidence) and background (Supporting Evidence) components of the Independent Review. Literature that met the specific inclusion criteria was critically appraised and the outcomes were summarised narratively. Details of the literature that was excluded from the review are listed in the appendices.

Objectives

The objectives of this report are as follows:

1. To repeat the systematic literature search from a comprehensive review of the evidence commissioned by NHMRC in September 2012, to capture any additional evidence published between October 2012 and May 2014. The purpose of the repeat systematic literature search is to determine whether there is evidence to establish that emissions from wind farms cause human health effects (Direct Evidence).
2. To review evidence submitted during the public consultation process on the NHMRC draft Information Paper: *Evidence on Wind Farms and Human Health*, with the purpose of identifying any Direct Evidence not already identified by the repeat systematic literature search, any Background Evidence relevant to the issue of wind farms and human health, plus any Mechanistic or Parallel Evidence that considers similar emissions from wind farms in the laboratory or other exposure settings and reports on one or more health (or health-related) outcomes (Supporting Evidence).

Methods

The methods described below cover the repeat systematic review search, data extraction and critical appraisal for the Direct Evidence component; and the data extraction and critical appraisal for the Supporting Evidence component of the review. We have used the inclusion criteria specified by ONHMRC, and have followed the methods and forms used in the Independent Review for data extraction and critical appraisal.

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[2] Details on the NHMRC website at http://consultations.nhmrc.gov.au/public_consultations/wind_farms.

Criteria for considering studies for inclusion

To be classified as 'included' in the systematic component of the review (i.e. Direct Evidence), the evidence had to:

1. be publicly available in English;
2. be based on systematically collected data relevant to wind farms and human health;
3. look at human exposure to wind farm emissions;
4. not exclusively select participants only because they had reported health effects;
5. compare participants with different levels of exposure to wind turbines (e.g. a "near" group and a "far" group);
6. explain how the data were collected;
7. report on one or more health (or health-related) outcomes; and
8. analyse the results.

The questions to be addressed in the Direct Evidence component of the review relate to distance, audible noise, infrasound and low-frequency noise, shadow flicker, and EMR (as detailed in Appendix 1).

Search methods for identification of studies

Electronic searches

We searched the following sources to identify peer-reviewed literature meeting the inclusion criteria for the systematic review (Direct Evidence) component: PubMed, Embase, *The Cochrane Library*, PsycInfo and health-related categories of Web of Science. The sources and search strategies replicated those used in the Independent Review, and covered the period from the date the original searches were conducted (i.e. October 2012 to May 2014). The full details of the search strategies for the databases listed above are given in Appendix 2. Searches were run across all four databases on 19 March 2014 and again on 7 May 2014 to capture any additional studies, and to ensure the review is as up-to-date as possible.

Data collection and analysis

Selection of studies for Direct Evidence

Citations identified in the repeat literature search were imported to EndNote and duplicates removed. One reviewer (SM) undertook an initial screening of titles and abstracts to exclude those citations that were very obviously outside the scope of the review. Two reviewers (GB and MS) then independently screened the titles and abstracts of the remaining 'possible' citations and classified each citation as 'potentially included' or 'excluded'. Citations to any material that had been considered for the Independent Review were excluded at this stage. The full-text of citations deemed potentially eligible were retrieved and independently assessed for inclusion. Disagreements were resolved through discussion within the wider team.

The final list of potentially eligible studies for inclusion in the Direct Evidence component of the review was circulated to the Reference Group. Following clarification on the scope of the review with the Reference Group and ONHMRC on 21 May, the final list of potentially eligible studies was agreed. The list was further refined and the selection of studies completed following a meeting with the Reference Group at the NHMRC office in Canberra on 2 July 2014.

Citations that did not meet the inclusion criteria specified above were excluded and the reason for exclusion recorded. At the request of the Reference Group, excluded studies were also considered for the Supporting Evidence component of the review.

Selection of studies from the Submissions for Supporting Evidence

For the citations submitted during the public consultation (24 February to 11 April 2014), we applied the inclusion criteria for both the Direct Evidence and Supporting Evidence components of the review, and classified the material as 'included' or 'excluded'. Evidence was classified as 'included' in the Direct Evidence component of the review if it met the conditions specified in the 'Criteria for considering studies for inclusion' section above.

To be classified as 'included' as Background Evidence in the Supporting Evidence component of the review, the evidence had to:

1. be publicly available in English;
2. be based on systematically collected data relevant to wind farms and human health;
3. explain how the data were collected; and
4. analyse the results.

Where relevant, to be 'included' as Mechanistic or Parallel Evidence in the Supporting Evidence component of the review, the evidence had to meet the conditions specified above and also had to:

1. be peer-reviewed; and
2. report on one or more health (or health-related) outcomes.

The questions addressed in the Supporting Evidence component of the review are detailed in Appendix 3.

Any material that was considered in the Independent Review was excluded (that is, citations listed under *References* and *Appendix C – Excluded Articles* in the Independent Review report). Where background material did not meet the criteria specified above it was excluded and the reason for exclusion recorded.

Data extraction and assessment of methodological quality

For the additional literature classified as 'included' in the Direct Evidence component of the review, two reviewers (GB and EW) independently undertook critical appraisal and data extraction. The steps followed were similar to the methodology outlined in the Independent Review report, namely:

1. Relevant data were extracted from each article/study into a standardised form, using the modified NHMRC Data Extraction Table; and

2. The overall methodological quality of each article or study was critically appraised (i.e. consideration of the level of evidence[3] and likelihood of chance, bias and confounding) using the NHMRC 'Checklist for appraising the quality of studies of aetiology and risk factors'[4] as a guide.

We also undertook critical appraisal and data extraction of the additional literature classified as 'included' in the Supporting Evidence component of the review, using the format: aim; design; exposure; outcome; limitations; results; and conclusions.

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[3] Level I – IV specified in the NHMRC Evidence Hierarchy. Available at:

https://www.nhmrc.gov.au/_files_nhmrc/file/guidelines/developers/nhmrc_levels_grades_evidence_120423.pdf

[4] Box 9.1. Available at: https://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/cp65.pdf.

Synthesis

The two components of the review (Direct Evidence and Supporting Evidence) were synthesised separately.

For the Direct Evidence, we grouped studies by the type of emission or exposure being investigated (as outlined in Appendix 1) and narratively summarised the key findings. We noted any particular concerns or limitations of the studies' ability to inform the assessment of wind farms as a cause of adverse health effects. Where possible, we commented on the reliability of the evidence of the association between the type of emission and adverse health effects, and considered the strength of the association, its relationship to the level of exposure and the possible explanations for the association (if found).

For the Supporting Evidence, studies investigating Mechanistic and Parallel Evidence were synthesised separately. Studies deemed eligible for Background Evidence considered emissions from wind turbines, and the extent to which exposure to these emissions varies by distance and other characteristics. These studies were grouped according to the type of emission being investigated (mostly noise and infrasound). Where appropriate, we identified common themes from among the Mechanistic and Parallel studies, and summarised these narratively, noting particular limitations of the studies and their ability to help inform the review.

For both components of the review, the substantial heterogeneity between the studies, both in terms of their design and the exposures or outcomes assessed, precluded any form of quantitative analysis.

Results

Repeat systematic literature search for Direct Evidence

The combined bibliographic database searches yielded 1597 references after de-duplication. Following title and abstract screening, 1526 citations were excluded as being clearly out of scope of the review. Of the remaining 71 citations, nine had previously been considered and either included or excluded from the Independent Review; these nine citations were therefore excluded from any further consideration in this update.

The remaining 62 citations were independently assessed against the inclusion criteria. Forty-nine citations were excluded, mostly because the citation was not based on systematically collected data relevant to wind farms and human health, or the outcomes were not health or health-related. The complete description of reasons for exclusion is reported in Appendix 4.

Of the remaining 11 citations, six potentially eligible citations were initially included as Direct Evidence from the repeat systematic literature search. During the process of critical appraisal and data extraction, three of these citations (Bockstael 2012; Ruotolo 2012; Whitfield Aslund 2013) were deemed not to meet the criteria and, following clarification on the scope of the review from the Reference Group, were excluded from the Direct Evidence component. Two of the excluded citations (Bockstael 2012; Ruotolo 2012) met the criteria for Background Evidence and Mechanistic Evidence, respectively, and are assessed in those sections of the report. The three included citations of Direct Evidence identified from the repeat searches were Mroczek 2012, Pohl 2012 and Taylor 2013a. (Five additional citations, representing three separate studies, were identified for inclusion under Direct Evidence through the public consultation process and are discussed further in the Submitted literature section of the report.)

At the request of the Reference Group, we checked all excluded citations for their eligibility for the Supporting Evidence component of the review (i.e. Background, Mechanistic or Parallel Evidence), and identified ten Supporting Evidence citations (reporting ten separate studies) in this way. (Five of these were also included in the Submitted Literature following public consultation.)

The steps involved in assessing the identified literature from the searches and the flow of references through the selection process are summarised in Figure 1.

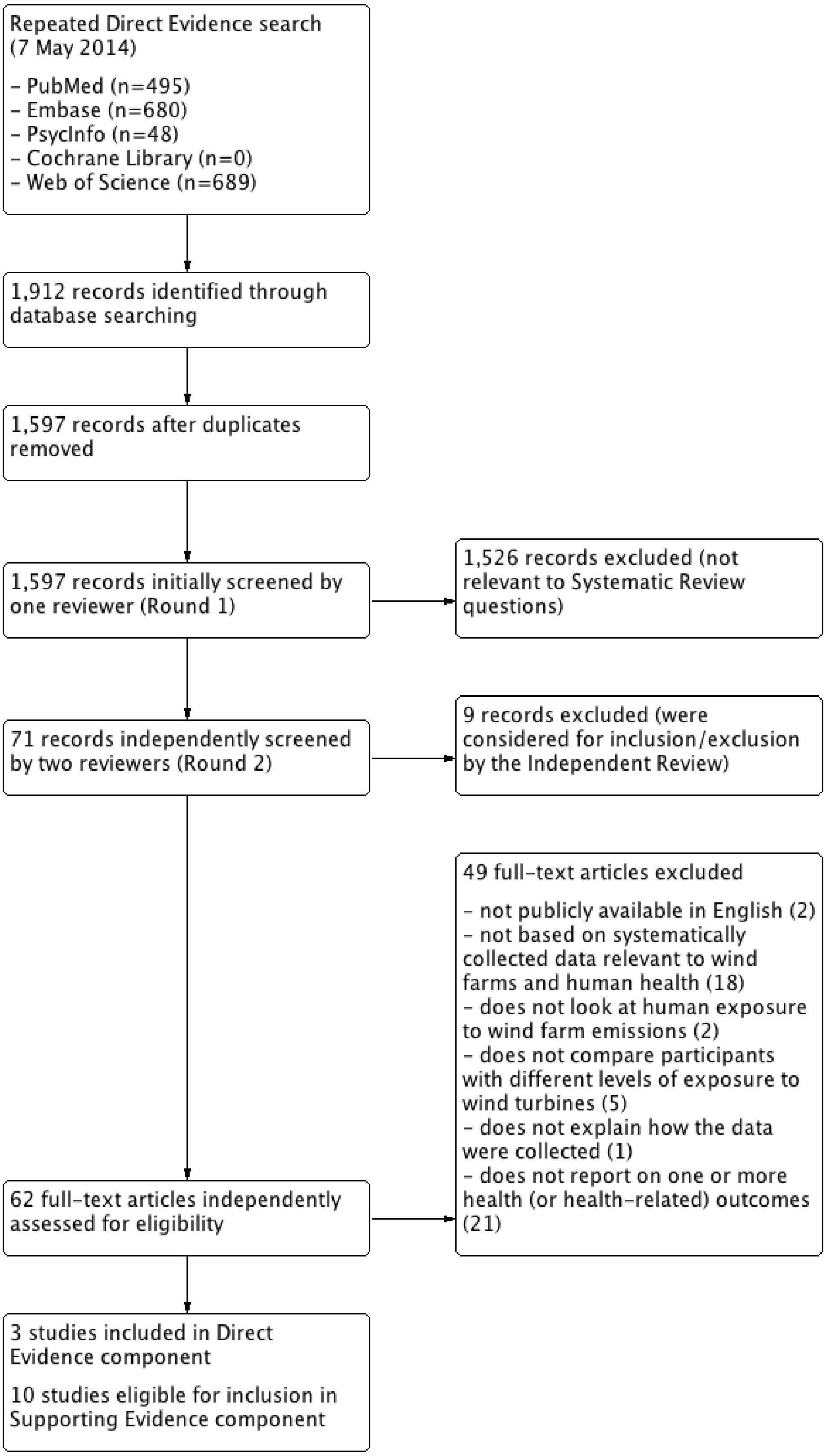

Figure 1. Flow chart showing screening and selection of studies from repeat systematic literature search

Submitted literature (‘the Submissions’)

Following the period of public consultation (24 February to 11 April 2014) on the NHMRC draft Information Paper: *Evidence on Wind Farms and Human Health*, we were provided with a list of additional evidence comprising 249 citations (from 36 submissions). In the first instance, we checked these citations against the Independent Review to see if they had been considered in the review, and if so, in which section. Citations appearing in the References or Appendix C of the Independent Review had previously been considered (and either included or excluded from the Independent Review) and so did not need to be considered further (Group 1). Citations listed in Appendix D of the Independent Review had already been considered (and excluded) for the systematic review (Direct Evidence) component, so only needed to be assessed for the Supporting Evidence component of the review (Group 2). None of the remaining citations was listed in the Independent Review and these citations were therefore considered for inclusion in both the Direct Evidence and Supporting Evidence components of the review (Group 3).

The 249 submitted citations were considered and grouped as follows:

- Group 1: excluded from Direct Evidence and Supporting Evidence (n = 25)
- Group 2: assessed for Supporting Evidence only (n = 48)
- Group 3: assessed for Direct Evidence and Supporting Evidence (n = 176)

The 224 citations in Groups 2 and 3 were independently assessed against the inclusion criteria. An initial screen was based on a review of title and abstract. The full-text of those deemed possibly relevant was retrieved to determine which citations should be included in the Supporting Evidence component of the review. Of the 224 citations, 192 were excluded (reasons for exclusion are reported in Appendix 5).

Following clarification on the scope of the review from the Reference Group, four citations were deemed eligible for the Direct Evidence component of the review (Kuwano 2013; McBride 2013; Paller 2013; Yano 2013). (These citations comprised three conference papers and one Masters Thesis, which explains why they were not identified through the updated systematic review search.) Two other citations included in the submissions, which were eligible for the Direct Evidence component (Mroczek 2012; Taylor 2013a), had already been identified through the updated systematic review search.

One citation submitted during public consultation (Janssen 2011) had previously been excluded from the Independent Review, however at the request of the Reference Group this study was re-assessed and subsequently included as Direct Evidence. This paper provides further analysis of data from multiple studies that were included in the Independent Review and provides an extension of their results.

Twenty citations (reporting 16 separate studies) met the criteria for the Supporting Evidence component of the review and have been grouped according to Background Evidence (shadow flicker, noise, infrasound, annoyance, EMF); Mechanistic Evidence and Parallel Evidence. Five additional citations were already identified through the repeat literature search as eligible for the Supporting Evidence component (Crichton 2013, Crichton 2014, Doolan 2013, Taylor 2013b, Tickell 2012).

The steps involved in assessing the submitted literature and the flow of references through the selection process are summarised in Figure 2.

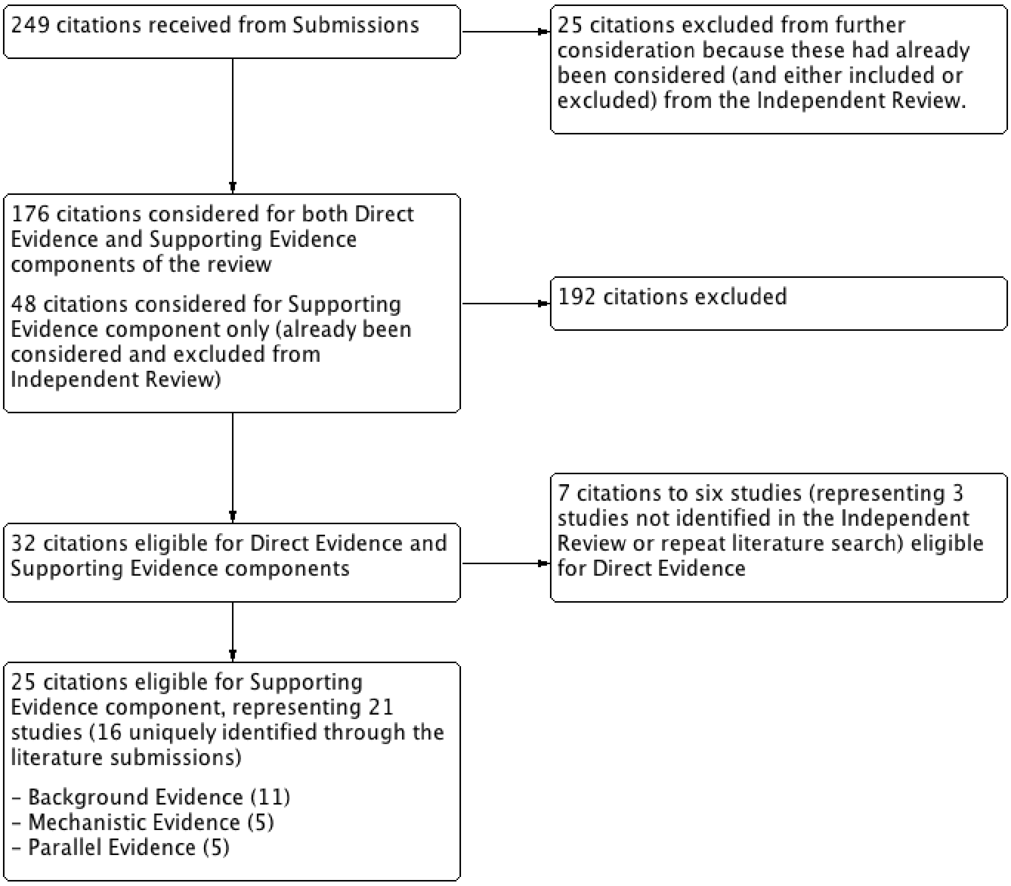

Figure 2. Flow chart showing screening and selection of submitted literature citations

Summary of studies of Direct Evidence

After review of the full papers, eight citations, representing six unique studies, met the criteria for the systematic review (Direct Evidence) component of this updated review of wind turbines and health. Since Yano 2013 is a further analysis of data collected by Kuwano 2013, we treated these as citations to the same study[5]. The Janssen 2011 paper provides further analysis of data from multiple studies that were included in the Independent Review, and is therefore not treated as a separate study. We used the modified NHMRC data extraction form (the same form that was used for the Direct Evidence papers in the Independent Review) to critically appraise and extract data for each study (see Appendix 6). A summary of the characteristics of the included studies is provided in Table 1a and a summary of the results in Table 1b.

Limitations

It is important to note that all these studies (apart from Janssen 2011) were published since the literature searches for the Independent Review were completed in September 2012. Consequently this update only reflects the literature over a period of about 18 months, and not the entire literature on this topic. In addition, while many of the included studies were identified by undertaking a systematic search of the literature, not all papers were accessed via the repeat systematic search. For example, Janssen 2011 was an excluded paper in the Independent Review, which was included in the submissions from the public consultation and re-assessed for this update at the Reference Group's request. Furthermore, not all

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[5] From here on, Kuwano 2013 is used to refer to both citations.

studies have been published. The study by Paller 2014, for example, is a Master's thesis and considered 'grey literature'. Therefore, the conclusions in this report are much more cautious than if this was a systematic review of only published papers unrestricted by date or language of publication.

Summary characteristics

All studies included in the Direct Evidence component of the review were cross-sectional in design. The studies were conducted in New Zealand, the United Kingdom, Japan, Canada, Sweden, The Netherlands, Germany and Poland. Importantly, no study was conducted in Australia. Therefore, likely sociocultural differences between people in these countries and Australians make it difficult to draw conclusions about generalisability or applicability of findings in these studies to the Australian context. Of the studies reporting demographic characteristics, there was an approximately equal sex ratio, and the mean age of study respondents ranged from 46 to 56 years.

The studies mostly examined wind farm noise or proximity to wind farms and a wide range of self-reported outcomes, as follows:

- One study assessed self-reported annoyance and estimated level of wind farm noise (Kuwano 2013).
- One citation provided further analysis of data on self-reported annoyance and estimated level of wind farm noise (Janssen 2011) from three studies included in the Independent Review.
- One study assessed self-reported annoyance and exposure to wind farm markings (Pohl 2012).
- Two studies assessed self-reported physical symptoms (e.g. headache, nausea, tinnitus) and estimated level of wind farm noise (Taylor 2013a) or proximity to wind farms (Paller 2014).
- Four studies assessed aspects of self-reported mental health (stress, irritability, psychological distress, anxiety and depression) and estimated level of wind farm noise (Kuwano 2013; Taylor 2013a), proximity to wind farms (Paller 2014), or exposure to wind farm obstruction markings (Pohl 2012).
- Two studies assessed self-reported sleep quality and estimated level of wind farm noise (Kuwano 2013) or proximity to wind farms (Paller 2014).
- Four studies assessed quality of life, satisfaction with living environment or life satisfaction and estimated noise exposure or proximity to wind farms (Kuwano 2013; McBride 2013; Mroczek 2012; Paller 2014).

In all studies, health and health-related outcomes were self-reported by participants; that is, none of the outcomes was objectively measured (e.g. by using a test administered or performed by a doctor or scientist) or used medical records or health service linkage data. Widely used, validated instruments were used in some studies (e.g. SF-12, WHOQOL-BREF, GHQ and PSQI), but none of these measures was used in more than one study. Due to the wide range of outcomes, it was difficult to assess consistency in results across studies for a particular outcome, with annoyance being the most common single outcome investigated, although varying instruments were used to measure this outcome across the studies.

Study quality and bias

Based on the assessment of study quality, all studies with the possible exception of the Janssen 2011 analyses were considered to have limited capacity to inform the assessment of wind turbine noise or proximity of wind farms as a cause of any of the outcomes investigated in the studies. All studies were cross-sectional studies, so it cannot be determined objectively whether wind farm exposure preceded the self-reported outcomes.

There was potential for selection bias in almost all studies as response rates were generally low and limited information was presented on characteristics of non-responders or how non-responders differed from responders. Recall bias was likely in three of the studies identified in this review (Paller 2014; Pohl 2012; Kuwano 2013) and in the studies analysed by Janssen 2011, as it was impossible to blind participants to the nature of the study purpose. Recall bias was unclear in the remaining three studies. No study adjusted for all relevant confounders (including age, gender, education, chronic disease, and economic factors).

The reasons why confidence in the results was considered moderate for Janssen 2011, which combined data from three previously published studies, are that it had a clear and limited set of objectives, large sample size, acceptable recruitment rates in two of the three included study samples, and robust measurement of exposure. However, problems of the cross-sectional nature of the design, assessment of one outcome (annoyance) using a non-validated self-reported outcome measure, and lack of adjustment for all relevant confounders still apply.

Results

Measures of wind turbine exposure were very variable in these studies, ranging from simple proximity and estimated noise exposures to quantitative noise exposure metrics based on actual noise measurements. Most studies investigated some aspect of noise exposure, but no studies specifically examined infrasound, shadow flicker or EMR. One study (Pohl 2012) examined wind turbine markings.

After assessing the overall findings, the methodologies used and the limitations in study quality in the six studies (and further analysis of previous studies in the Janssen 2011), the following are our responses to the specific questions to be addressed by our updates to the systematic review in relation to distance, audible noise, infrasound and low frequency noise, shadow flicker and EMR:

> Is there any reliable evidence of an association between the emission/exposure from wind turbines and adverse health effects? If so, how strong is this association? How does the strength of this association relate to distance from wind turbines? And might this association be explained by: chance, bias, or confounding.

1. Distance

Only two studies (Paller 2014; Mroczek 2012) used distance or proximity as the sole measure of exposure to wind turbines, rather than assessments based on specific emissions. Mroczek 2012 was able to assess distance-response relationships, but found that quality of life (QOL) was higher for those closer to wind turbines, although no clear reason was found for this apparent counter-intuitive finding. Of the very large number of outcomes investigated by Paller 2014, only two (sleep quality and vertigo) were found to be worse in residents closer to wind turbines, while no associations were found for all other outcome measures. However, due to the many limitations in this study—including the survey distribution method, low response rate, potential biases such as selection bias and information bias and mapping of rural addresses and industrial wind turbine locations—little weight can be given to these findings. Therefore, it is concluded that there is no reliable evidence of an association between distance from wind turbines and adverse health effects in the papers included in the systematic (Direct Evidence) component of our review.

2. Audible noise

The noise level from wind turbines was the most common emission to be examined in these studies. The Janssen 2011 analyses provided the most convincing evidence for an association between noise levels and indoor and outdoor annoyance levels, including an exposure-response relationship, but the relationship is not strong when compared with the associations of wind-turbine visibility or economic benefit from wind farms with annoyance. The study described by Kuwano 2013 provided some very weak evidence supporting this association (between noise levels and annoyance), but also found that other factors, such as pre-existing beliefs about wind turbines (e.g. they disturbed the landscape), moderated this effect. Although Taylor 2013a did not investigate annoyance, the findings suggested it was the perception of noise rather than actual noise exposure that was associated with symptoms of ill-health, and that this relationship was stronger in those who had a personality characterised by negative affectivity and intolerance of negative emotion and events.

McBride 2013 also did not investigate annoyance, but found that QOL was poorer in some of its domains in participants living closer to wind turbines; a finding which is the converse of Mroczek 2012. For no other outcomes investigated in these studies was there any relevant evidence. Thus, while Janssen 2011 provides the most robust evidence of an association between wind turbine noise and annoyance, the association is not strong, but does demonstrate an exposure-response relationship and chance, bias and confounding are less likely to influence these findings than in the other Direct Evidence studies we reviewed. For no other outcome investigated in these studies is there reliable evidence of an association.

3. Infrasound and low-frequency noise

No studies investigated infrasound as such and so no conclusions can be drawn about associations between infrasound from wind turbines and any health or health-related outcomes.

4. Shadow flicker and other visual stimuli

No studies investigated shadow flicker and so no conclusions can be drawn about associations between shadow flicker from wind turbines and any health or health-related outcomes.

One study (Pohl 2012) investigated exposure to wind farm obstruction markings and provided some weak evidence that different types of lights were more or less annoying. Given this preliminary finding, this characteristic of wind turbines warrants further investigation.

5. Electromagnetic radiation

No studies we reviewed investigated EMR and so we can draw no conclusions about associations between EMR from wind turbines and any health or health-related outcomes.

Conclusions of studies of Direct Evidence

Noise from wind turbines was the most commonly investigated emission. We found there was weak evidence in support of an association between noise levels and annoyance, including an exposure-response relationship. This association was not strong and was affected by other factors, including wind turbine visibility, financial benefits and pre-existing beliefs. One small survey raised the possibility that perception of noise (rather than actual noise) predicts adverse health effects. Based on two cross-sectional studies, we found no reliable evidence of an association between distance from wind turbines and adverse health effects. No studies investigated the adverse health effects associated with infrasound as such, shadow flicker or EMR from wind turbines.

Table 1a – Characteristics of Included Studies (Direct Evidence)

Study ID	**Janssen 2011** (This is a further analysis of data collected by three studies reviewed in the Independent Review)	**Kuwano 2013**	**Yano 2013** (This is a further analysis of data collected by Kuwano 2013)	**McBride 2013**	**Mroczek 2012**	**Paller 2014**	**Pohl 2012**	**Taylor 2013a**
Aim	"… to derive the exposure response relationship between wind turbine noise exposure in A-weighted equivalent noise level (L*den*) and the expected percentage annoyed residents and to compare it to previously established relationships for industrial noise and transportation noise."	"… conducted a series of physical measurements, laboratory psychological experiments and social surveys of wind turbine noise… In this paper, a design of questionnaire used in the survey and a part of the results are introduced."	"The objectives are to propose the representative dose-response curves for wind turbine noise in Japan and to investigate the effects of moderating factors on annoyance caused by wind turbine noise."	"…this study was carried out to study how health-related quality of life (HRQOL) changes over 2 years in a community living within 2 km of a turbine installation and compares HRQOL in a control group over the same period."	"To assess how the quality of life is affected by the close proximity of wind farms."	"The objectives of this study were to explore the association between proximity to industrial wind turbines and self-reported health effects, specifically quality of life (both physical and mental health) and sleep disturbance, in residents living close to wind turbines."	"…this research aims to analyse whether [wind turbine] obstruction markings have the potential to cause substantial annoyance in general or influence only a sensitive minority."	"This paper aims to answer the following questions: is any link between wind turbine noise and non-specific symptoms (NSS) reporting due to actual noise levels from the turbine, or individuals' perceptions of noise?"
Study type	Cross-sectional study N = 1820 (combined across three previously published studies)	Cross-sectional study N = 511 (366 exposed, 145 not exposed)	Cross-sectional study N = 511 (366 exposed, 145 not exposed)	Cross-sectional study in the same population that was examined by Shepherd 2011. (Sample size of exposed or not exposed group not provided)	Cross-sectional survey N = 1277	Cross-sectional study N = 396	Cross-sectional survey N = 420	Cross-sectional survey N = 138

Study ID	**Janssen 2011** (This is a further analysis of data collected by three studies reviewed in the Independent Review)	**Kuwano 2013**	**Yano 2013** (This is a further analysis of data collected by Kuwano 2013)	**McBride 2013**	**Mroczek 2012**	**Paller 2014**	**Pohl 2012**	**Taylor 2013a**
Characteristics of population and study setting	One study in an agricultural setting in southern Sweden, another in a mixture of urban and rural settings in Sweden, and the third in a mixed setting in the Netherlands. Proximity to wind turbines not specified for the two Swedish studies; exposed participants in the Dutch study were within a 2.5 km radius from wind turbines. Mean age = 51.5 years Male = 46%	No information provided about characteristics of respondents or the setting, but assumed to be the same as Yano 2013, which was based on the same sample. Approximately equal sex ratio, c. 80% over 50 years (c. 30% over 70 years)	Respondents lived 90 m to 1466 m apart from the closest wind turbine, in various locations from Hokkaido to Okinawa in Japan.	Setting was the Makara Valley in New Zealand, hilly terrain with long ridges 250 m to 450 m above sea level. Exposed participants were recruited from 56 dwellings situated within a 2 km radius from a single wind turbine, while the non-exposed / controls resided > 10 km from turbine installation.	Polish population living within various distances of wind turbines (< 700 m to > 1500 m) at a number of different locations. Included a group unaware of plans for wind farm in their neighbourhood. Mean age = 46 years ± 16 years (range 18 to 94) Male = 55%	Respondents were located within 0.4-55,000 m* of the largest wind farms in each of eight counties in Ontario, Canada. [* as reported by the author, but assumed to mean 0.4 km to 55 km] Median age = 56 years, male = 52%, 79% married, median income $60,000, 59% post-secondary education.	Southern German population living within 8 km of wind farms, with line of sight view of turbines. Mean age = 51 years Male = 57%	Population of two cities in English Midlands living within 500 m of eight micro turbines and within 1 km of four small turbines. Mean age = 54 years ± 16 years (range 20 to 95) Male = 55%
Exposure considered	No information provided about wind farm details or exposures. Annual day/evening/night L*den* was calculated from the wind turbine noise emission data in the original three	No information provided about wind farm details or exposures considered, but assumed to be the same as Yano 2013, which was based on the same study	Exposure group consisted of residents from 36 “target sites” with audible wind turbine noise. Distance was used as a crude surrogate for noise exposure of wind	Exposed participants resided within a 2 km radius from a single wind turbine. Wind farm details: 66 turbines (Siemens SWT-2.3-82 VS), turbine height 125 m, rotor	Exposure to wind farms (noise levels not reported). Distance was used as a crude surrogate for noise and visual exposure of wind turbines. No details of wind	The number of turbines ranged from 18 to 110 turbines per farm and turbine installed capacity ranged from 1.5 megawatt (MW) to 2.3 MW.	Exposure to wind farms (with view of turbines within line of sight). Median wind farm characteristics: 8 WT; height 138 m; power 14 MW; time in operation	Exposure to wind turbines. Residences located within 500 m of 0.6 kW micro turbines, or within 1 km of 5 kW small turbines. Specific exposure

Study ID	**Janssen 2011** (This is a further analysis of data collected by three studies reviewed in the Independent Review)	**Kuwano 2013**	**Yano 2013** (This is a further analysis of data collected by Kuwano 2013)	**McBride 2013**	**Mroczek 2012**	**Paller 2014**	**Pohl 2012**	**Taylor 2013a**
	studies. Assumptions were made about wind velocity of 8 m/sec, a neutral atmosphere and noise at 10 m, in line with recommendations by European regulatory agencies.	sample. Exposure group consisted of residents from 36 "target sites" with audible wind turbine noise. Control group consisted of residents at 16 control sites where wind turbine noise was inaudible and no turbines were visible.	turbine. Regular electricity generation of wind turbines was from 400 kW to 3,000 kW. The average sound pressure levels $L_{Aeq,n}$ in decibels was measured with sound levels ranging from 26 dB to 50 dB. Control group consisted of residents at 16 control sites where wind turbine noise was inaudible but no turbines were visible.	diameter 82 m. (See Shepherd 2011) Typical noise exposure, measured as $L_{95(10mins)}$ ranged from 20 dB(A) to 54 dB(A). Non-exposed / control group were selected from 250 homes located in a socioeconomically and geographically matched area differing from the exposure group only by distance from wind turbines (≥ 10 km).	farms provided except the number of wind farms in the provinces from whom respondents were drawn. There is no information about how many wind farms were in proximity to the close (< 1500 m) respondents and location. Five exposure groups determined by approximate distance from turbines: < 0.7 km (17.2%); 0.7 km to 1 km (21.9%); 1 km to 1.5 km (17.3%); > 1.5 km (33.2%); plus a group (6.7%) that knew nothing about plans for wind farm in their neighbourhood, which was not apparently drawn from any specific distance group, although it is inferred that they	Distance between respondent's home and nearest wind turbine was assessed using geocoding (ArcGIS) - ranked by percentile (1st percentile to 100th percentile) and then divided into 4: quartile 1 < 25th percentile, quartile 2 < 50th, quartile 3 < 75th and quartile 4 < 100th percentile – and compared to self-reported distances. The reference group for the analyses was the group in the quartile furthest away from the wind farms.	40 months. Five groups of markings: three types of day markings; simple versus complex landscape scenery; day and night markings; synchronised versus non-synchronised markings; with and without light intensity adjustment. No non-exposed groups included.	details: Modelled sound pressure in A-weighted decibels with a sound map with 1 m grid over map area. Grid plane located 1.5 m above ground. No non-exposed groups included.

Study ID	**Janssen 2011** (This is a further analysis of data collected by three studies reviewed in the Independent Review)	**Kuwano 2013**	**Yano 2013** (This is a further analysis of data collected by Kuwano 2013)	**McBride 2013**	**Mroczek 2012**	**Paller 2014**	**Pohl 2012**	**Taylor 2013a**
					were a subset of the > 1500 m group. Apart from this group, no non-exposed groups.			
Effects or outcomes considered	Indoor and outdoor annoyance, measured using a one-item self-report scale (four-point scale in both the Swedish studies and a five-point scale in the Dutch study).	Self-reported satisfaction with living environment (shopping convenience, transportation, amount of greenery, clean air, quietness, public facilities). Self-reported degree of annoyance of road traffic noise, aircraft noise, high-speed train (Shinkansen) noise, conventional train noise, noise from factories, construction noise and wind turbine noise (five step categories). Self-reported trouble with sleep.	Annoyance related to wind turbine noise evaluated by ICBEN 5-point verbal scale: extremely, very, moderately, slightly or not at all.	The WHOQOL-BREF (26-item version) measured physical (seven items), psychological (six items), and social (three items) HRQOL, an additional eight item domain measuring environmental QOL and two 'generic' items asking about general health and overall quality of life. Two amenity items were included.	Self-reported health-related quality of life using General Health Questionnaire (Short Form-36) and Visual Analogue Scale (VAS) for health assessment.	Pittsburgh Sleep Quality Index (PSQI) SF-12 The Satisfaction with Life Scale (SWLS) Wind Turbine Syndrome (WTS) Index using eight questions drawn from the Quality of Life and Renewable Energy Technologies Study survey. Frequency of the following symptoms in the past month: headache, irritability, concentration problems, nausea, vertigo, undue tiredness, tinnitus.	Stress indicators: general impact; annoyance; annoyance changes over the years; psychological and somatic symptoms; behaviour; coping response.	Self-reported outcome measures: positive affectivity; negative affectivity; neuroticism; discomfort intolerance; emotional intolerance; non-specific somatic symptoms.

Study ID	**Janssen 2011** (This is a further analysis of data collected by three studies reviewed in the Independent Review)	**Kuwano 2013**	**Yano 2013** (This is a further analysis of data collected by Kuwano 2013)	**McBride 2013**	**Mroczek 2012**	**Paller 2014**	**Pohl 2012**	**Taylor 2013a**
Are the study participants well defined in terms of time, place and personal characteristics? **[exposure misclassification]**	Place: Not specified for the two Swedish studies; within a 2.5 km radius from wind turbines in the Netherlands study Personal characteristics: age, gender, noise sensitivity, economic benefit, living on rural and flat terrain. 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).	No information provided, but assumed to be the same as Yano 2013, which was based on the same study sample.	Place: respondents lived 90 m to 1466 m apart from the closest wind turbine, in various locations from Hokkaido to Okinawa in Japan. Personal characteristics: no specific demographic details, but elderly residents reportedly over-represented in study sample. 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).	Place: participants were from the Makara Valley in New Zealand, and resided either < 2 km (exposed) or ≥ 10 km (control) from a wind turbine. Personal characteristics: no information on demographic details. Time: this is a two-year follow-up of a previous cross-sectional survey of the same community (different sample). As self-reported outcome measures were used, it cannot be determined objectively whether wind farm exposure preceded the reported outcome(s).	Partly—in terms of place Personal characteristics: age, gender, education and occupation. Place: residents live within different distances from turbines: < 0.7 km; 0.7 km to 1 km; 1 km to 1.5 km; > 1.5 km; the latter including a group that knew nothing about plans for wind farm in their neighbourhood. Time: this is a cross-sectional study with self-reported exposure and outcome measures; therefore, it cannot be determined objectively whether wind farm exposure preceded the reported outcome(s).	Place: respondents were located within 0.4 m to 55,000 m* of the largest wind farms in each of eight counties in Ontario, Canada. Personal characteristics: age, gender, county, marital status, income and education level were collected, but only the age, gender and county were used for adjustment in some analyses. Time: cross-sectional study undertaken between February and May 2013; as self-reported outcome measures were used, it cannot be determined objectively whether wind farm exposure preceded the reported outcome(s). [* as reported by the	Partly—in terms of place Personal characteristics: age, gender, duration in house, home ownership, marital status, education, occupation (including working from home and in the wind business) and income. Place: residents live within 8 km of wind turbines, with view of turbines within line of sight. 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).	Partly – in terms of place Personal characteristics: age and gender Place: residents live within 500 m of eight 0.6 kW micro turbine installations and within 1 km of four 5 kW small wind turbine installations. 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).

Study ID	**Janssen 2011** (This is a further analysis of data collected by three studies reviewed in the Independent Review)	**Kuwano 2013**	**Yano 2013** (This is a further analysis of data collected by Kuwano 2013)	**McBride 2013**	**Mroczek 2012**	**Paller 2014**	**Pohl 2012**	**Taylor 2013a**
						author, but assumed to mean 0.4 km to 55 km]		
What percentage of individuals or clusters refused to participate? **[selection bias]**	The two Swedish studies had participation rates of 68% and 58%, while participation in the Dutch study was 37%. There is potential for sample selection bias due to low response rate in the Dutch study.	No information provided, but assumed to be the same as Yano 2013, which was based on the same study sample. There is potential for sample selection bias due to low response rate.	49% of exposed group participated (n = ~366, calculated), 45% responded (n = ~145, calculated). High potential for selection bias due to low response rate. Sampling area determined by distance from wind turbines.	The sample sizes of the exposed and control groups were not reported, nor the response rates. Insufficient detail about the recruitment process and response rate to evaluate selection bias. Response rates in 2010 survey were poor, and response/selection bias may have been more likely in 2012 survey than in 2010 survey because blinding to purpose of the later study likely less effective.	Subjects randomly chosen using a two-stage sampling technique. No information provided about whether participants were blinded to the purpose of the study. Unable to determine response rate as size of initial sampling frame not reported and number of refusals and non-contacts not reported. Sampling area determined by distance from wind turbines, but unknown whether there is differential participation rates at various distances from wind farms (which may be evidence of	The survey questionnaire was sent to 4,876 residences, with 412 returned (8.5% response rate) of which only 396 (8.1%) were included due to incomplete data. High potential for selection bias due to low response rate, which also varied by county.	100 to 200 questionnaires were distributed to households near each of 13 wind farms. Average response rate = 25% (range 11% to 39%). High potential for selection bias due to low response rate. Sampling area determined by distance from wind turbines. Incentive to participate was 15 EUR or entry in a lottery.	89% of those who received a questionnaire did not complete and return it. The low response rate suggests likely selection bias. Attempt to gauge likely degree of participation bias by asking how they feel about wind power has little validity. Sampling area determined by distance from wind turbines.

Study ID	Janssen 2011 (This is a further analysis of data collected by three studies reviewed in the Independent Review)	Kuwano 2013	Yano 2013 (This is a further analysis of data collected by Kuwano 2013)	McBride 2013	Mroczek 2012	Paller 2014	Pohl 2012	Taylor 2013a
					possible selection bias). Lack of data on non-responders could also contribute to selection bias.			
Are outcomes measured in a standard, valid and reliable way? **[outcome misclassification]**	Non-validated measures of annoyance used. Outcomes self-reported.	Outcomes are self-reported, and no information has been provided about validation of measurements.	Use of ICBEN five-point verbal scale to rate annoyance due to wind turbine noise (unclear if this is a validated tool). Outcomes are self-reported.	General health and overall quality of life were measured using the WHOQOL-BREF (26-item version) measured physical (seven items), psychological (six items), and social (three items) HRQOL, an additional eight item domain measuring environmental QOL and two 'generic 'items asking about general health'. There is a high probability of exposure misclassification (exposure time not well-defined), and outcome	Use of SF-36 and VAS as tools for quality of life was well described. Outcomes self-reported.	Health outcomes were measured using a number of scales and surveys, however it is unclear whether these are validated instruments.	Overall, only low misclassification of outcomes is expected due to the methods and scales. Outcomes self-reported.	Positive and negative affectivity measured by using a modified scale. Neuroticism, frustration intolerance and nonspecific somatic symptoms used self-report scales.

Study ID	**Janssen 2011** (This is a further analysis of data collected by three studies reviewed in the Independent Review)	**Kuwano 2013**	**Yano 2013** (This is a further analysis of data collected by Kuwano 2013)	**McBride 2013**	**Mroczek 2012**	**Paller 2014**	**Pohl 2012**	**Taylor 2013a**
				misclassification (amenity questions apparently not validated instruments).				
What percentages of individuals or clusters recruited into the study are not included in the analysis (i.e. loss to follow-up)?	The two Swedish studies had participation rates of 68% and 58%, while participation in the Dutch study was 37%. In the Swedish studies, respondents were not found to differ from the population in the study areas on age and gender (other characteristics not reported). Early vs late respondents were reported not to differ in their answers, but no data on this were reported. In the Dutch study, 200 non-responders were sent a questionnaire about annoyance	Unknown. Response rates were not provided, but assumed to be the same as Yano 2013, which was based on the same study sample. No information was presented on characteristics of non-responders or how non-responders differed from participants. Loss to follow up not relevant as cross-sectional study.	Unknown. No information was presented on characteristics of non-responders or how non-responders differed from participants. Loss to follow up not relevant as cross-sectional study.	Unknown. Response rates were not provided. No information was presented on characteristics of non-responders or how non-responders differed from participants. Loss to follow up not relevant as cross-sectional study.	Unknown. Response rates were not provided. No information was presented on characteristics of non-responders or how non-responders differed from participants. Loss to follow up not relevant as cross-sectional study.	Survey questionnaire sent to 4,876 residences, with 412 returned (8.5% response rate) of which 396 (8.1%) were included due to incomplete data. No information was presented on characteristics of non-responders or how non-responders differed from participants. Loss to follow up not relevant as cross-sectional study.	Unknown. No information was presented on characteristics of non-responders or how non-responders differed from participants. Loss to follow up not relevant as cross-sectional study.	Unknown. No information was presented on characteristics of non-responders or how non-responders differed from participants. Loss to follow up not relevant as cross-sectional study.

Study ID	**Janssen 2011** (This is a further analysis of data collected by three studies reviewed in the Independent Review)	**Kuwano 2013**	**Yano 2013** (This is a further analysis of data collected by Kuwano 2013)	**McBride 2013**	**Mroczek 2012**	**Paller 2014**	**Pohl 2012**	**Taylor 2013a**
	(48% responded); no differences in annoyance were found between this group and the study participants. Loss to follow up not relevant as cross-sectional study.							
Recall bias?	Given the nature of the survey it is implausible that participants would have been blinded to its purpose.	Given the nature of the survey it is implausible that participants would have been blinded to its purpose.	Given the nature of the survey it is implausible that participants would have been blinded to its purpose.	Uncertain. Participants were blinded to study purpose in original survey but authors acknowledge participants possibly unblinded in present survey due to publicity associated with original survey.	No information is provided about whether participants were blinded to the purpose of the study. Unknown whether respondents influenced by renting their land for wind farm construction and use.	Information bias is likely, as the self-reported distance from the nearest wind farm was grossly underestimated. No blinding was possible.	Yes. The study purpose was not masked and an incentive to take part was offered, so responder bias may have been enhanced.	Uncertain. The study purpose was not masked. Findings stronger for perceived noise exposure, rather than calculated noise exposure, which could suggest recall bias.
Confounding? (other factors that could affect the outcomes)	Age, sex, noise sensitivity, economic benefit, visibility of wind turbine, and living in rural and flat terrain were adjusted for in	No information provided by authors about addressing confounders. Another factor that could affect the outcomes is that	No information provided by authors about addressing confounders.	Socioeconomic and geographic matching and adjustment by length of residence were undertaken. Detail about	Plausible confounders that were not addressed include socio-economic status, occupation, chronic diseases and risk	Some collected demographic information (education, income, marital status) were not used for adjustment in	Multiple potential confounders were considered in the analysis, but others, such as socio-economic status (SES) were not.	Discussion of confounders was limited, and no adjustments were provided on likely confounders such as employment,

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	models used in the study. However, data on some other potentially important confounders, such as socioeconomic status, medical status, other potential sources of annoyance and country, were either not collected or adjusted for in the analyses. Therefore, confounding may have affected the results, as annoyance can be influenced by a wide range of lifestyle, demographic, health and environmental factors.	there is potential for misclassification of exposure (duration of exposure not quantified).		recruitment, selection and matching not provided, but plausible confounders not addressed in previous (and nor presumably this) report include age, education, chronic disease and risk factors for chronic disease, occupation, employment, background noise, and turbine visibility.	factors for chronic diseases.	analyses, and so could have affected the outcomes. Other potential sources of confounding likely to have affected the results are the health outcomes, such as quality of life, symptomatology, sleep and life satisfaction as they are influenced by a very wide range of health, demographic, lifestyle and environmental factors.		economic benefit from wind turbines etc.
Chance?	There was only one outcome (although this was for annoyance both inside and outside, so there were two variables) and only one exposure measure (L*den*).	No statistical tests for differences were performed.	Possibility of spurious significant associations arising by chance cannot be excluded as multiple statistical tests were conducted. No mention of	Statistical tests for differences were performed; however there was no mention of statistical adjustments for multiple testing.	Possibility of spurious significant associations arising by chance cannot be excluded as multiple statistical tests were conducted. No mention of	Large number of analyses likely to have been undertaken given the number of wind farms, outcome measures and their component variables. No	Possibility of spurious significant associations arising by chance cannot be excluded as multiple statistical tests were conducted.	Possibility of spurious significant associations arising by chance cannot be excluded as multiple statistical tests were conducted.

Study ID	**Janssen 2011** (This is a further analysis of data collected by three studies reviewed in the Independent Review)	**Kuwano 2013**	**Yano 2013** (This is a further analysis of data collected by Kuwano 2013)	**McBride 2013**	**Mroczek 2012**	**Paller 2014**	**Pohl 2012**	**Taylor 2013a**
	Thus there was not an excessive number of analyses in the paper, which reduces the potential for chance to explain the associations found.		statistical adjustments for multiple testing.		statistical adjustments for multiple testing.	correction for multiple comparisons was undertaken. Thus, chance cannot be excluded as an explanation for at least some of the associations found.		
Overall quality of the study to determine whether wind farms cause adverse health effects?	The design of this pooled study had some strengths over much of the other published epidemiological wind turbine research, such as having a clear and limited set of specific objectives, the large sample size of 1820 participants, acceptable recruitment rates (at least for the two Swedish studies, rather than the Dutch study), robust exposure metrics based on measured data and high quality	There was no difference between exposure and control groups in reported satisfaction with living environments. More exposed group respondents reported wind turbine, road traffic and 'other' noise as the most annoying in their environment, and trouble sleeping due to (non-specified) noise. However the reliability of the results are limited by the overall quality of the study	Though directionality of dose-response measurements are as expected (i.e. the prevalence and severity of annoyance increased with increasing sound level), the study was cross-sectional in design and so does not permit definitive conclusions regarding causation and health outcomes, in this case annoyance due to wind turbine noise. In addition, bias is likely due to	There was little difference evident in WHOQOL scores among exposed residents in 2010 and 2012. In the current survey, exposed residents scored significantly lower than (2012) control residents in the physical domain (p = 0.043). Answers to the amenity questions indicated no significant difference in scores over time, however there was a significant decrease in amenity in the 2012 control group compared with the	Cross-sectional design does not permit conclusions regarding causation between quality of life and wind farms. The finding that QOL was inversely related to distance of home from a wind farm was unconvincing given the lack of data regarding responders living near wind farms receiving rent from wind farm operators. Due to major potential confounders not being considered, and the potential	The study design had some strengths, however other aspects, including the execution, were poor. The very low participation rates, the use of some non-validated instruments (e.g. symptom reporting and the Wind Turbine Syndrome (WTS) index), lack of data on potentially important confounders weakened the quality of the study. In addition, most health outcomes did not appear to	This study was cross-sectional in design. This does not permit any conclusions regarding causation and health outcomes, in this case annoyance, from wind turbines. However, the results are consistent and the findings of the research robust. This study has limited capacity to inform the assessment of wind turbine obstruction markings as a cause of adverse health effects.	Perception of noise, rather than actual noise exposure, is important in predicting symptoms of ill-health. This relationship is stronger in those who have personality characterised by negative affect, and intolerance of negative emotion and events. However this finding is not convincing given the low response rate, lack of description of non-responders and use of

Study ID	Janssen 2011 (This is a further analysis of data collected by three studies reviewed in the Independent Review)	Kuwano 2013	Yano 2013 (This is a further analysis of data collected by Kuwano 2013)	McBride 2013	Mroczek 2012	Paller 2014	Pohl 2012	Taylor 2013a
	reporting in the paper. Conversely, there were some weaknesses, such as the cross-sectional design, using non-validated self-report outcome measures of annoyance and noise sensitivity, pooling data from three different studies from two different countries (with inevitable differences in methods used, although these are small) and lack of data on potentially important factors which may influence annoyance. Overall confidence in the results is considered moderate.	which is considered poor due to several aspects, including bias from self-reported outcomes, low recruitment rate and lack of statistical testing. The study design was cross-sectional which does not permit any conclusions about causation, and it is unclear whether the reported differences between control and exposed groups are associated with wind turbine noise. Generalisability of findings is likely limited due to over-recruitment of elderly residents, and cultural / contextual differences between Japan and Australia. This study has very	self-reported outcomes and recruitment method. Generalisability of findings is likely limited due to over-recruitment of elderly residents, and cultural / contextual differences between Japan and Australia. Overall, this study has very limited capacity to inform the assessment of wind turbine noise of adverse health effects.	2010 control group (p = 0.034). The overall quality of the study is considered poor due to, among other things, the high probability of recall bias, exposure and outcome misclassifications, and confounding. In addition, this study has a repeat cross-sectional design, it however does not permit definitive conclusions regarding causation and health outcomes. Therefore, this study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.	for recall and selection bias, and chance associations, this study has an overall poor quality rating. This study has very limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.	have a relationship with distance from a wind farm, and the two findings for which there appeared to be an association, could be explained by chance, bias or confounding. Therefore, it is unlikely that the findings of this study have any clear implications in relation to the question of proximity of wind farms and human health.		modelled noise exposure instead of actual measurements for relatively small wind turbines. In addition, the cross-sectional design does not permit any conclusions regarding causation and health outcomes. This study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.

Study ID	**Janssen 2011** (This is a further analysis of data collected by three studies reviewed in the Independent Review)	**Kuwano 2013**	**Yano 2013** (This is a further analysis of data collected by Kuwano 2013)	**McBride 2013**	**Mroczek 2012**	**Paller 2014**	**Pohl 2012**	**Taylor 2013a**
		limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.						

Table 1b – Results of Included Studies (Direct Evidence) and Commentary

Study ID	**Results**	**Commentary (by Authors of this review)**
Janssen 2011	In the adjusted models there was a small positive association between noise level and indoor annoyance. There was significant variability between the three studies, with lower annoyance in the Swedish studies. Visibility of the wind turbines had a considerably stronger positive effect than for the noise level, while self-reported noise sensitivity was only weakly associated with noise. Annoyance was found to be strongly reduced for economic benefit. A similar pattern of associations was found for outdoor annoyance. Repeating the analyses taking out those who did not benefit economically and not taking the individual study effects into account resulted in a steeper slope of the relationship between noise and annoyance for both indoors (B = 5.50) and outdoors (B = 5.48). Dose-response curves show that noise levels up to about 35 dB caused almost no annoyance for both indoors and outdoors. The authors estimated that an L*den* of 45 dB resulted in 12% annoyed participants indoors and 26% annoyed participants outdoors. It should be noted that the numbers of highly annoyed participants indoors and outdoors were very small (specific numbers not reported) and this, coupled with small numbers exposed above 45 dB, resulted in wide error bars at the higher noise levels. For both indoors and outdoors, a 1 dB increase in L*den* was estimated to increase annoyance by about three points on a 100-point scale. No confidence intervals or p-values given.	This paper, comprising pooled data from three European cross-sectional studies of wind turbine noise and annoyance, is a little stronger than most other Direct Evidence papers included in this review. In particular, participation rates were reasonable for two out of the three studies and noise measurement was robust. There were some weaknesses in the annoyance measurement and other factors, such as noise susceptibility, which were based on self-report and insufficient consideration of confounders. The most reliable conclusion from this study is that there is a small, but statistically significant association between self-reported annoyance and wind turbine noise. There is also a consistent dose-response relationship between increasing noise and increased annoyance. The relationship is similar for indoor and outdoor annoyance. The other interesting finding is that factors such as economic benefit and visibility are suggested to have a stronger effect on annoyance, reducing and increasing annoyance respectively.
Kuwano 2013	No statistical tests were reported for this study. According to the study authors, there appeared to be some difference between wind turbine site respondents and control area respondents in the satisfaction of quietness in their environmental surroundings. The authors also noted that more control site respondents reported no concerns with noise compared with wind turbine site respondents, and more wind turbine site respondents reported that wind turbines were the most annoying	This cross-sectional survey does not permit any reliable conclusions about causation and it is unclear whether the reported differences between control and exposed groups are associated with wind turbine noise. The aim of the study was to conduct a social survey of wind turbine noise using a questionnaire that had been developed to examine responses to environmental noise. The study compared an 'exposed' group of residents from sites with audible wind turbine noise and a

Study ID	Results	Commentary (by Authors of this review)
	sound in their environment. However, more wind turbine respondents also nominated road traffic noise or "other" noise as their most annoying noise, suggesting that the wind turbine areas surveyed may have a different overall noise profile compared with control areas. It appeared that somewhat more wind turbine site respondents reported trouble with sleep, but more wind turbine site respondents also did not answer this question. According to the authors, wind turbine noise respondents who had trouble sleeping were more likely to report noise as the reason; however what type of noise was not investigated and earlier questions indicated that this group were troubled more than control groups by other types of noise as well as wind turbine noise.	control group where no wind turbines were visible and no noise from turbines was audible. The survey design does not associate reported outcomes to measured wind turbine noise, and the overall noise profile of control areas and wind turbine areas may be systematically different in other ways. No data were reported to determine whether poorer sleep or greater annoyance could be attributable to the degree of noise exposure in the 'exposed' group. Lack of statistical testing makes it difficult to determine if differences between control and exposed groups are likely to be due to chance. The low recruitment rate indicates possibility for recruitment bias and over-recruitment of elderly residents limits generalisability to the broader population. The context of the survey is poorly described, but it is likely to be very different to the Australian context of wind turbine exposure, limiting generalisability to the Australian context. This study has very limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.
Yano 2013	This study presented annoyance-distance and annoyance-noise (LAeq) curves based on survey data which the authors describe as indicating the dose-response relationship between wind turbine exposure and annoyance response among nearby residents. While the specific p-values were not reported, the authors indicated that respondents were significantly more likely to be "more extremely annoyed than others" by wind turbines if they reported being "interested in environmental problems", thought that "wind turbine generator was not a good method" and viewed them as "disturbing the landscape". Self-reported "sensitivity to sound" was also associated with greater propensity to report being extremely annoyed by wind turbines. Annoyance at sites with sea wave sound was significantly lower than that at sites without, and the authors suggested this was because of masking of turbine noise by sea wave sound. There was no significant difference in exposure-annoyance relationships between colder and warmer areas.	The purpose of this cross-sectional survey was to investigate the effects of moderating factors of annoyance caused by wind turbine noise. This study does not permit any conclusions about causation because it cannot be determined that exposures precede outcomes. Self-reported exposures and outcomes are likely to be subject to reporting bias and recruitment bias is also likely. Overall noise profile of control areas is likely to be systematically different to wind turbine areas in ways other than presence of turbines. Over-recruitment of elderly residents limits generalisability to broader population. Although context is poorly described, differences between Japanese and Australian contexts likely limit generalisability to Australia. This study has very limited capacity to inform the assessment of wind turbine noise on adverse health effects.

Study ID	Results	Commentary (by Authors of this review)
McBride 2013	Two-year follow up of a previous cross-sectional survey carried out on individuals living within two kilometres of industrial wind turbines compared with a matched control group (Shepherd 2011). This study was conducted in the same community as the 2010 survey, but with a different sample. There was little difference evident in WHOQOL scores among exposed residents (Makara, NZ) in 2010 and 2012. In the current survey, exposed residents scored significantly lower (i.e. poorer) than control residents in the physical domain (Mann-Whitney U test p = 0.043). Examination of individual WHOQOL questions revealed that exposed residents scored significantly lower (i.e. poorer) on the question, "How satisfied are you with your health?" (p = 0.020). Answers to the amenity questions indicated no significant difference in scores over time, however, there was a significant decrease in amenity in the 2012 control group compared with the 2010 control group (p = 0.034).	This cross-sectional study was carried out to compare health-related quality of life (HRQOL) in both a community living within 2 km of a wind farm and a control group, with the results of a similar survey conducted two years earlier. Although it replicates the previous cross-sectional study in the same community, the study does not permit conclusions regarding causality. Therefore, it is unknown if the exposure preceded the self-reported health and amenity outcomes. Also, given that the outcomes are based on self-report, it is plausible that pre-existing opinions about the turbine installation in question, or about wind turbines in general, may have influenced participant recruitment and self-reported outcomes. While the overall health of the exposed group was self-reported as being significantly poorer than the control group in the 2012 dataset, this difference between groups was small and potentially influenced by factors other than exposure to the turbine, given that other confounders were not taken into account in the analysis. Follow up of individuals in comparison to communities would have been more beneficial. This study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.
Mroczek 2012	Quality of life (QOL) within all subscales was reported to be highest by the respondents living the closest to wind farms and lowest by those living farther than 1,500 m from a wind farm (and by those who did not know about the plans for construction of a wind farm in their neighbourhood). People living more than 1,500 m from a wind farm assessed their vitality (V) significantly lower than those living the closest distance from a wind farm (p < 0.05). Within the mental health (MH) subscale, the respondents living the closest distance from a wind farm assessed their QOL significantly higher compared to those living between 1,000 m to 1,500 m or more from a wind farm (p < 0.05 in both cases). The distance between a place of residence and a wind farm also had a statistically significant effect on QOL scores within the social functioning (SF) and the	This study was cross-sectional in design and does not permit any conclusions regarding causation between QOL and wind farms. The results of this study indicate that close proximity to wind farms does not result in a deterioration of QOL. However, the finding that QOL was inversely related to distance of home from a wind farm was unconvincing given the lack of data regarding responders living near wind farms receiving rent from wind farm operators. Other biases and confounders were not addressed and this study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.

Study ID	**Results**	**Commentary (by Authors of this review)**
	role functioning-emotional (RE) subscales ($p < 0.05$). A regression analysis found that various socio-demographic and health variables (including whether respondents worked, learned or had a farm) within the subscales had only limited influence on how respondents perceived their QOL.	
Paller 2014	A statistically significant association between the logarithm of distance and the Pittsburgh Sleep Quality Index (PSQI) was found when controlling for age, gender and county, with sleep improving with greater distance from the wind farm (adjusted R-Squared = 0.08 and $p = 0.01$ for the adjusted model were the only ways that these findings were presented). Among the eight Wind Turbine Syndrome (WTS) index variables, the relationship between vertigo and the logarithm of distance was statistically significant when controlling for age, gender and county, with vertigo worse among participants living closer to the wind farm (adjusted R-Squared = 0.11 and $p < 0.001$ for the adjusted model were the only ways that these findings were presented). Distance-response relationships were presented for those outcomes shown to be associated with the logarithm of distance (PSQI and vertigo) or close to being statistically significant (tinnitus $p = 0.08$). While no data were presented for a similar analysis of WTS index, it is stated in the text that there was no association with the logarithm of distance, but vertigo was one of the variables used in this index. There was no significant difference across each of the eight wind farms, and for each of the quartiles of distance from a wind farm, for the following outcomes: Physical Component Score (PCS) and Mental Component Score (MCS) of the SF-12, depression, Satisfaction With Life Scale (SWLS), Wind Turbine Syndrome (WTS) index, headache, irritability score, concentration problems, nausea, undue tiredness, tinnitus or sleep quality.	While the serious limitations in design, execution, analysis and presentation in this Master's Thesis make interpretation of these findings difficult, most health outcomes did not appear to have a relationship with distance from a wind farm. The two findings for which there appeared to be an association (poorer sleep quality and vertigo) could be explained by chance, bias or confounding. Therefore, it is unlikely that the findings of this study have any clear implications in relation to the question of proximity of wind farms and human health.

Study ID	Results	Commentary (by Authors of this review)
Pohl 2012	This study, which considered stress responses to aircraft obstruction markings on wind farms, found no evidence of substantial annoyance caused by the obstruction markings. According to the study authors, residents exposed to xenon lights reported more intense and multifaceted stress responses than those exposed to LED or colour markings on blades, however p-values were not reported. The authors also considered that synchronised navigation lights were found to be less annoying than non-synchronised lights under certain weather conditions, and that light intensity adjustment seemed to be advantageous. The respondents 'strain during the planning and construction phase' appeared to have a moderating on the relationship between research conditions (day marking, synchronisation, intensity adjustment, landscape scenery) and annoyance. The stress factor of a wind farm that was rated most annoying was changes to landscape scenery, followed by wind turbine noise. While p-values were not reported, the authors state that annoyance caused by night and day markings was significantly lower than these factors.	This study was cross-sectional in design. This does not permit any conclusions regarding causation and health outcomes, in this case annoyance, from wind turbines. However, the results are consistent and the findings of the research robust. The study has limited capacity to inform the assessment of wind turbine obstruction markings as a cause of adverse health effects.
Taylor 2013a	Respondents living in areas with low probability of hearing turbine noise had higher Positive Affectivity (mean = 2.86; SD = 1.05) than those living in areas with moderate (mean = 2.38; SD = 1.21) or high (mean = 1.97; SD = 1.04) probability of hearing turbine noise ($F_{2,118} = 6.40$; partial $g^2 = 0.10$; $p < 0.01$). Two-step hierarchical regression analyses were carried out to examine the moderating impact of Negative Oriented Personality (NOP) traits on the perceived noise loudness – reported symptom relationship. The simple slope analyses showed that the link between perceived loudness and symptoms reporting only occurred at high levels of discomfort intolerance (b = 3.954, t = 3.4815, p < 0.001) and emotional intolerance (b = 1.921, t = 1.677, p < 0.096). However, the simple slope analyses examining the link between perceived loudness and symptoms reporting did not reach significance at any level of Negative Affectivity.	This paper investigated whether any association between wind turbine noise and reporting of non-specific symptoms (NSS) was attributable to actual noise levels or an individual's perceptions of noise. The overall finding was that perception of noise rather than actual noise exposure is important in predicting symptoms of ill-health, and that this relationship is stronger in those who have personality characterised by Negative Affectivity and intolerance of negative emotion and events. However this finding is not convincing given the low response rate, lack of description of non-responders, and use of modelled noise exposure instead of actual measurements for relatively small wind turbines. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.

Study ID	Results	Commentary (by Authors of this review)
	A second series of five hierarchical regression analyses examined the interaction between calculated actual noise from the turbine and NOP traits on symptom reporting. Calculated actual wind turbine noise did not affect symptom reporting directly or interactively.	

Summary of studies of Supporting Evidence

Thirty citations, representing 26 unique studies, met the criteria for the Background, Mechanistic and Parallel Evidence components of the review (15 Background studies; six Mechanistic studies; five Parallel studies). Twenty-one of these studies were identified from the submissions (Submitted Literature) and five from the repeat systematic literature search. A summary of the characteristics of the included studies is provided in Table 2.

Since the identification of these studies depended on submissions received during the public consultation, and was thus not the result of a systematic search of the literature, their findings may not be representative of the complete body of evidence from published studies relevant to their topics. At best, these studies represent a snapshot of (mostly) recent research in this area.

Background Evidence

The fifteen studies were grouped according to the type of emission being investigated. Noise and infrasound accounted for seven and five studies, respectively. Shadow flicker, annoyance and electromagnetic field (EMF) were each the subject of one study. Collectively, the studies were concerned with measuring exposure levels from wind turbines and how these levels vary by distance and other characteristics (e.g. terrain, climate, etc.). The following question was addressed:

> For each such emission from wind turbines (i.e. noise, infrasound, flicker or EMR), 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?

1. Noise

Bockstael 2012 reported that factors which may influence annoyance from wind turbines were angular blade velocity, nacelle position (wind direction) and relative humidity. The fluctuation indicator, developed in the study, was related to noise with “not at all annoyed” at noise levels in the low 40 dB(A) range to “extremely annoyed” at the high 90 dB(A) range. Level of exposure from a wind turbine in the study was 42.8 dB(A) at 17 rotations of the blade and measured levels were slightly higher than the calculated levels.

Doolan 2013 reported measurements made at 2.5 km and 8 km from a wind turbine. Measurements were in the 10 Hz to 30 Hz frequency band and the broadband up to 1000 Hz, using three metrics to assess exposure to overall noise. Overall noise levels were found to be low and at the level of detectability and ranged from 39 dB(Unweighted) to 67 dB(Unweighted) and 30 dB(A) to 34 dB(A) for broadband noise. For the 10 Hz to 30 Hz band the noise level ranged from 36 dB(Unweighted) to 66 dB(Unweighted). No link could be made between the noise data and the operation of the wind turbine. Three subsequent publications reporting on this study (Zajamsek 2013a, 2013b, 2014) refined the recording technique proposed by Doolan by additional microphones and measurement locations. Local wind speed was found to be more important for annoyance at the house 2.5 km from the turbine than at 8 km. At 8 km distance, time of day was found to be more important for annoyance than wind speed and direction.

A report by the EPA South Australia in 2013 (EPA SA 2013) for the Waterloo Wind Farm measured both audible noise and infrasound at six locations 1.3 km to 7.6 km from the wind farm. Audible noise was detected at two homes but at very low levels. For downwind conditions the levels outside of the residences were 29 dB(A) to 39 dB(A), compared with 27 dB(A) to 30 dB(A) measured during upwind conditions outside of the residences. The recommended evening and night time limit of 20 dB(A) was met for 99% of the time (inside of the residences) when the wind turbines were in operation. Extensive information was provided regarding variation of G, A and C-weighted noise by wind speed, direction and shutdown periods.

Evans 2013 reported on pre-operational and operational low frequency noise (LFN) and infrasound at the Macarthur wind farm. A-weighted and un-weighted sound levels for LFN were measured indoors at two farms 1.8 km and 2.7 km from the wind farm. Measurements undertaken at three operating conditions (no turbines, 105 and 140 turbines), and the effects of varying hub height and wind direction speeds were assessed. Almost all noise levels were below 30 dB(A) with only seven ten-minute periods out of 23 nights of monitoring exceeding the low frequency noise criteria developed by the UK Department for Environment, Food and Rural Affairs (DEFRA). No information was provided regarding attenuation by distance.

The study by Møller 2011 was an extensive noise survey of LFN from 48 wind turbines to assess penetration into indoor spaces. Factors investigated included effects from wind speed, directivity, sound insulation of the building, noise versus turbine size, ground reflections, distance from turbine, window configuration (open or closed) and atmospheric effects. Different factors may increase or decrease sound at the receiver with wind speed, directivity, distance and turbine size all potentially increasing noise. The authors state: “The minimum distance, where a 35 dB limit is complied with, varies considerably between the large turbines, even when the turbines are relatively equal in size (2.3–3.6 MW). The distance varies from slightly over 600 m to more than 1200 m.”

Schiff 2013 investigated outdoor LFN at five measurement locations near 84 wind turbines in rural western New York state. Two control sites were chosen, but data from one control site were discarded. Data were provided on the predicted variation of noise with distance as reported in the pre-construction environmental impact assessment, e.g. if distance to three nearest turbines was 663 m, 813 m, and 856 m (location A) then the noise level was 38 dBA, compared to 48 dBA where the three nearest turbines were located at 219 m, 427 m and 666 m (location D). Extensive results were presented for the measured change in noise level for different wind speeds at 10-minute intervals. At measurement location A, the un-weighted low frequency noise levels were 48.7 dB at 1m/sec and 64.7 dB at 7m/sec wind speed. The A-weighted measurements at location A were 33.2 dB(A) and 44.8 dB(A) for wind speeds of 1 m/sec and 7 m/sec respectively. At location D the noise levels were slightly higher, but lower at the other three locations. The noise exposure at the five receptor locations was generally ordered by the distances to nearby turbines. No information was provided regarding the effects of terrain or wind direction.

A consultant report by Walker 2012 (also reported in Schomer 2013) provides details of LFN measurements at three homes at distances between 0.4 km and 5.6 km from wind farms. Extensive ten-minute measurement results were reported, with 50 dB in the frequency range 16 Hz to 25 Hz, measured at the residence located 1280 feet (0.4 km) from a wind turbine. Information regarding variation in terrain and distance separating wind turbine from residences was limited. Although the distances to various turbines were reported, only overall turbine noise at each home was reported.

2. Infrasound

The EPA SA 2013 report included infrasound results for various wind speeds and wind directions, both inside and outside of residences at the six locations. For downwind conditions, the levels outside of the residences were 61 dB(G) to 64 dB(G), compared with 51 dB(G) to 58 dB(G) inside of the residences. The infrasound levels for upwind conditions ranged from 54 dB(G) to 59 dB(G) outside of the residences, compared with 45 dB(G) to 50 dB(G) inside the residences.

In Evans 2013 the measured infrasound levels during the operational monitoring stage typically ranged from 40 dB(G) to 70 dB(G), increasing as the wind speed at the site increased (as was observed during the pre-operational and interim stages). All measured infrasound levels during the operational stage remained below the assessment criterion of 85 dB(G), with the vast majority of data points significantly lower than the criterion. No information was provided regarding variation with distance.

Møller 2011 only briefly discusses the effects of propagation of infrasound from wind turbines and gives some variation in sound due to distance. These results are 69.1 dB(G) at 629 m and 58 dB(G) at 822 m for turbines between 2.3 MW and 3.6 MW.

Schiff 2013 reported infrasound measurement results at five locations near 84 wind turbines in rural western New York. At the most affected location (location D), the un-weighted infrasound level increased from 53.4 dB with wind speeds of 1 m/sec to 82.8 dB for wind speeds of 7 m/sec. No information for wind direction, terrain or distance was presented.

Turnbull 2012 describe limited information related to wind farm infrasound and variation in distance. Infrasound levels reported for the Clements Gap wind farm were as follows: 72 dB(G) at 85m; 67 dB(G) at 185 m and 61 dB(G) at 360 m. Further results were reported for Cape Bridgewater wind farm: 66 dB(G) at 100 m and 63 dB(G) at 200 m. These levels of infrasound are all inaudible to humans.

Walker 2012 (also reported in Schomer 2013) reported measurements of infrasound at three homes at varying distances from a wind farm. Extensive ten-minute measurement results were reported for the second residence (1280 feet from the nearest turbine), with a sound level of 76 dB detected both indoors and outdoors for the frequency harmonics in the 0.7 Hz to 5.6 Hz range. Information regarding variation in terrain and distance separating wind turbines from residences was limited.

3. Flicker

The report by Brinckerhoff 2011 related to the effects of shadow flicker where effects are only likely to occur within 10 times the rotor diameter of wind turbines. Factors that may affect shadow flicker are window widths in receiving houses, uses of affected rooms, intervening topography and intervening vegetation. No quantitation of these factors was provided.

4. Electromagnetic radiation

The report by McCallum 2014 described EMF measurements in the proximity of 15 vestas 1.8MW wind turbines. Results reported for three operational scenarios: high wind, low wind and shut-off. The levels reported were described in the abstract as follows: “Magnetic field levels detected at the base of the turbines under both the ‘high wind’ and ‘low wind’ conditions were low (mean = 0.9 mG; n = 11) and rapidly diminished with distance, becoming indistinguishable from background within 2 m of the base. Magnetic fields measured 1 m above buried collector lines were also within background (≤ 0.3 mG). Beneath overhead 27.5 kV and 500 kV transmission lines, magnetic field levels of up to 16.5 mG and 46 mG, respectively, were recorded. These levels also diminished rapidly with distance. None of these sources appeared to influence magnetic field levels at nearby homes located as close as just over 500 m from turbines, where measurements immediately outside of the homes were ≤ 0.4 mG.”

5.Vibration

Styles 2005 described ultra-low vibration amplitudes generated by wind farms for variation in wind speed, distance and mode of propagation. Clear harmonic components at multiples of 0.5 Hz were observed at 0.5 Hz to 7.5 Hz, at levels up to 250 nanometres per second, which were clearly vibrations from a wind turbine. Vibrations could be detected in excess of 10 km from a turbine, but amplitudes were very low.

Several studies (Maschke 2007; Qibai 2004; van Renterghem 2013; Tickell 2012) presented no new data regarding shadow flicker, EMR or variation of wind turbine noise in relation to characteristics, such as wind speed, distance or terrain.

Mechanistic Evidence

This section addresses the following question:

> Is there basic biological evidence that make it plausible that wind turbines cause adverse health effects?

There is some evidence from laboratory studies in psychology that positive and negative media reports and information exert a measurable effect on people's self-reported symptoms, mood and perceived wellbeing in response to laboratory-synthesised infrasound emissions (Crichton 2013; Crichton 2014). Although these studies were based on relatively small sample sizes, and in both cases subjects were university students, this is unlikely to negate the overall finding that psychological expectations can influence perception of effects of laboratory-synthesised wind farm exposures on wellbeing. This is broadly consistent with the findings of Chapman 2013 where, in a historical analysis of public complaints about wind turbine installations, the authors found that 15 of the 18 wind farms (83%) which have seen complainants have experienced local opposition from anti-wind farm groups. Although this study relied on imprecise estimates of the exposed population(s), this would not be sufficient to negate the principal findings.

Background noise may induce annoyance and also affect cognitive task performance in experimental settings. Ruotolo 2012 reported that audible wind farm noise was associated with annoyance and poorer performance when undertaking demanding cognitive tasks. However, the authors also found that annoyance was reduced when wind farm noise was accompanied by simulated video images of the wind farm. It is difficult to interpret the relevance of the findings to the present question but it seems likely that visual cues may be influential in certain noise-related effects and tends to support a psychogenic pathway.

It is important to note that Ruotolo 2012, Crichton 2013 and Crichton 2014 are all experimental studies that used small numbers of university students as participants. It is unclear how generalisable these results are to a broader population, and also whether these laboratory findings would apply in real world situations.

There has been very little research in community settings that helps to answer the question of whether wind turbine emissions could plausibly cause human health effects. Taylor 2013b reported the results of a cross-sectional noise and opinion survey among people living near micro wind turbine installations. Although this survey found an association between turbine noise and self-reported wellbeing and attitudes, the recruitment rate was extremely low (and this postal survey was likely subject to recruitment bias as well as retrospective/recall biases) and therefore its generalisability is questionable. Furthermore, being a cross-sectional study, the causality of relationships observed is difficult to determine. Kelley 1987 describes a method of gathering and organising opinion data about low frequency noises and for establishing thresholds of annoyance. Given that the published study included only seven participants, whose representativeness in relation to the general population was ill-defined, the specific thresholds reported in this paper are not considered likely to be a useful indicator of general community tolerance. This method could be applied to gauge community tolerance in a specific community, but the published example is unlikely to be representative of communities exposed to wind farms in general so its applicability to the present question is limited.

Taken as a whole, these studies of Mechanistic Evidence in humans did not find biological pathways by which wind turbine emissions might cause adverse health effects. However, they do indicate that wind turbine exposures may be associated with annoyance and that influences from the surrounding socio-cultural environment, such as media reports and local community attitudes, may influence how people perceive wind turbines and whether they attribute health effects to them.

Parallel Evidence

This section addresses the following question:

> Is there 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?

Experimental laboratory studies of exposure to low frequency noise in general have indicated that low frequency noise can affect annoyance, cognitive task performance, mood and sleep quality (Persson Waye 1997; Persson Waye 2001; Smith 2013). The remarks above in relation to the generalisability of experimental laboratory studies to broader populations and real world situations also apply to these studies. In addition, experimental exposures to synthesised low frequency noise (Persson Waye 1997; Persson Waye 2001) are unlikely to be equivalent with wind farm noise, and experimental exposure to simulated railway train pass vibration and noise (Smith 2013) would be expected to have very different characteristics. Therefore the applicability of this literature to the question of wind farm emissions is uncertain.

Other experimental evidence suggests that exposure to negative media reports about EMF exposure associated with Wi-Fi can induce symptoms via a 'nocebo' effect (Witthoft 2013). In this study, subjects perceived symptoms, related worries about EMF and reported anxiety, even during sham exposure. They also reported that the effect appeared to be magnified by an anxious disposition. Although the experimental design had some limitations, the main finding remains credible and agrees broadly with the psychological experimental literature described above, which suggests that psychogenic effects may be induced by expectations.

A cross-sectional survey of Taiwanese aerospace workers and noise exposure (Chao 2012) used echocardiography and audiometry to test the association between low frequency workplace noise and hearing loss and cardiac function. The authors concluded that hearing loss was greater for workers exposed to low frequency noise and that abnormality of left ventricular filling, as shown by an abnormal echocardiographic E/A ratio, was also higher in workers exposed to low frequency noise than that of the non-exposed control group. The study is of limited applicability because industrial noise exposure is most unlikely to be comparable to wind farm noise emissions. The generally poor scientific quality of this study also limits its value, e.g. selection of workers and how these were categorised into the three exposure groups was not described and potential confounders were not evaluated. In addition, the mechanism of how low frequency noise could affect left ventricular function is not clear from this study.

In summary, the Parallel Evidence included here indicates that low frequency noise in general may be perceived to be annoying, and may influence mood and performance on cognitive tasks in experimental laboratory situations. Although the experimental studies of Persson Waye were not specific to residential exposure to wind farm low frequency noise, similar effects may be plausible for wind farm exposures, particularly given their general consistency with the findings of other studies (Chapman 2013;

Crichton 2013; Crichton 2014; Ruotolo 2012). It is therefore plausible that external influences, such as media reports, community attitudes and even landscape visibility characteristics, could influence annoyance and exert psychogenic effects on subjective perception of health outcomes among those who believe they are exposed.

Evidence suggesting lower performance on demanding cognitive tasks in experimental laboratory settings is difficult to interpret; it is unclear if such effects, observable under experimental conditions, would also apply to real world settings. Given that the findings of reduced performance on cognitive tasks in laboratory settings tended to be accompanied by reports of annoyance and/or negative mood, it is possible that effects on performance are of psychogenic origin.

Conclusions of studies of Background Evidence

The Mechanistic studies do not provide reliable evidence that wind turbine emissions cause adverse health effects by biological pathways. However, they do indicate that exposure may be associated with annoyance, and that sociocultural factors, such as media and community attitudes, may influence people's perception of wind turbines and whether they attribute adverse health effects to them. The Parallel Evidence suggests that in experimental laboratory situations, low frequency noise may be perceived to be annoying and may influence mood and the ability to perform cognitive tasks. These findings may be plausible for wind turbine exposures. However, as with Mechanistic Evidence, external influences, such as media reports, community attitudes and landscape visibility characteristics, may also influence annoyance and exert psychogenic effects on subjective perception of health outcomes among those who believe they are exposed.

Table 2 – Characteristics of Included Studies (Background, Mechanistic and Parallel Evidence)

Background Evidence

Brinckerhoff 2011	**Design**	**Exposure**	**Outcome**	**Limitations**
Shadow Flicker				
Aim To update the evidence base regarding shadow flicker effects by stakeholder consultation survey and a review of international guidance material and academic literature. Shadow flicker modelling methods were also reviewed.	UK government report on shadow flicker including reviews of international guidance, and scientific literature, stakeholder survey and assessment of current methodologies used in the wind farm industry.	Large onshore wind turbines (approximately 500 kW upwards).	Stakeholder questionnaire survey results. Results of guidance and literature review. Results of review of shadow flicker modelling methods. Stakeholder questionnaires were completed by local planning authority (n = 17), developers and consultants (n = 14).	Poor response rate: the industry questionnaire was sent out to 178 company members on the mailing list of the industry association Renewable UK, only 14 responses obtained. Representativeness of industry stakeholders unknown. Two respondents were owners of wind turbines, four respondents were operators, and one respondent was involved in technical operations.
Results Review of other literature suggested that the health effects of shadow flicker show that light variations at frequencies below 2.5 Hz are unlikely to cause disturbances (generally wind turbine rotation frequency is 0.3-1 Hz). The report concluded that the frequency of shadow flickering associated with wind turbines is such that it should not cause a significant risk to health. Limited evidence suggests possible association between wind turbine flicker and epileptic seizures. In the UK, approximately 0.5% of the population suffers from epilepsy, and 3.5% to 5% of epileptics are susceptible to photosensitivity. However, the proportion of susceptible individuals (photo-sensitive epileptics who are specifically sensitive to low frequency flicker, i.e. 2.5 Hz to 3 Hz) is extremely small (less than 5% of photosensitive epileptics). The psychological and nuisance impact of shadow flicker does not constitute harassment, however under specific conditions of increased physical or mental demand and long-term exposure cumulative effects might meet criteria for significant nuisance. Stakeholder consultation indicated that shadow flicker has not been a widespread problem in the industry, yielding few complaints, generally resolved by implementing turbine shut down strategies. Mitigation measures which have been employed by operational wind farms, have proved very successful, to the extent that shadow flicker cannot be considered a major issue in the UK. Current pre-development site design measures to minimise shadow flicker also appear to have been successful. Current general recommendations to assess shadow flicker impacts within 130 degrees either side of north is considered acceptable, as is the 10 rotor diameter distance from the nearest property. However, the “one size fits all” approach may not be suitable at all latitudes.				

Review of computer shadow flicker modelling programs used by developers to assess shadow flicker indicated that the different shadow flicker modelling programs used produce similar results and because of simplification inherent in the modelling process (such as not considering wind speed and cloud cover variations), computer modelling produces 'worst case scenario' results and real-world experience is generally likely to be less extreme.

Quantitative measures are also specified in some guidelines stating that shadow flicker should not exceed 30 hours per year or 30 minutes a day. Responses to questionnaires show that developers view such guidelines as problematic due to latitudinal variations of impact and believe mitigation measures would be a better option in addressing the problem. The most common mitigation measures across countries are careful site design and turbine shut down periods. Other measures include blind installation, landscaping and vegetation screening.

Conclusion

Authors concluded "It is considered that the frequency of the flickering caused by the wind turbine rotation is such that it should not cause a significant risk to health."

Bockstael 2012	**Design**	**Exposure**	**Outcome**	**Limitations**
Noise				
Aim To investigate the relationship between wind turbine noise annoyance and exposure indicators, operational characteristics and environmental variables.	Field research at a wind turbine site in the Flemish part of Belgium over a six-month period. Environmental noise monitoring and resident's annoyance survey. Wind turbine annoyance was investigated in relation to possible exposure indicators, operational characteristics and environmental variables. Three households provided periodic reports of experienced annoyance (five point scale from 'not at all' to 'extremely annoyed') via a web application. Eight households were originally recruited via door-knocking.	Three wind turbines rated at 2 MW. Following previous complaints turbines were restricted to 600 kW during the night period (7pm–7am). Noise measurements were taken from two points in the back yard of one house approximately 270 m from the closest wind turbine. Operational characteristics of the closest wind turbine (such as angular blade velocity, electricity production and wind speed at hub height) and meteorological data (such as temperature and relative humidity) were also observed. Participants were asked to report annoyance levels via a web application.	Participant reported annoyance.	Limited number of participants in residents' annoyance survey . Representativeness unclear. Likely recruitment bias. Periodicity/frequency of resident reports unclear. Likely reporting bias as one household only reported when they were annoyed and five non-respondents reported lack of annoyance as the reason for non-response.

Results

552 reports of annoyance-level were provided by three of the recruited eight resident households over a four-month period. Three of the non-responders were telephone interviewed, one was not annoyed and the remaining two were annoyed from time to time but did not report it. Difference in noise sensitivity between responders and non-responders was not significant ($p > 0.05$, Fisher's Exact Test).

Predicted risk of annoyance was significantly related to blade velocity ($p < 0.0001$) and wind direction ($p < 0.001$). The risk of high annoyance increases with decreasing relative humidity ($p < 0.001$) from the air absorption effect on sound, a higher sound pressure level is expected with increasing humidity however is not consistent with observed decrease of annoyance, suggesting such an effect is not related to the propagation of sound but rather the weather.

Annoyance was found to be associated with directionality, with higher annoyance determined by certain conditions of angular blade velocity together with wind direction.

Conclusion

Authors concluded that the current study confirms that annoyance due to wind turbine noise is complex and influenced by personal and contextual variables as well as noise production and propagation. The authors also recommend that because directionality plays a role in noise annoyance, more subtle steering protocols and operational restrictions based on wind direction and angular blade velocity might help to reduce noise annoyance without cost-effectiveness detriment.

Doolan 2013	**Design**	**Exposure**	**Outcome**	**Limitations**
Noise				
Zajamsek 2013a **Zajamsek 2013b** **Zajamsek 2014** **Aim** To describe a new methodology to record noise annoyance inside residences near wind farms (Doolan 2013). To present preliminary results from upgraded noise and annoyance recording systems (Zajamsek 2014).	Noise surveys. The noise and annoyance monitoring system was placed in one house at a distance of 2.5 km (capacity 111 MW) from the wind farm for Doolan 2013 and Zajamsek 2013b. In the reports by Zajamsek 2013a and Zajamsek 2014 the noise and annoyance monitoring were undertaken in two houses, one at 2.5 km (capacity 129 MW) and the second at 8 km from the same wind farm. Location: Waterloo Wind Farm, South Australia.	In Doolan 2013 measurements of the A, Z (unweighted) and C-weighted sound level, and both the octave bands and narrowband format with a frequency resolution of 2 Hz, were recorded. Doolan only used one microphone; the later Zajamsek reports measure multiple locations simultaneously with an array of three and four microphones.	Overall sound pressure level versus annoyance rating by the resident. Doolan 2013 used a ten-point annoyance scale. The later Zajamsek reports used only '*Very Annoyed", "Moderately Annoyed", "Slightly Annoyed" and "Not Annoyed".*	All four studies were small studies with only one or two houses and therefore only a handful of subjects reporting annoyance. The noise recording system cannot identify noise sources, however the resident self-reported characteristics of the noise and weather conditions. Studies did not have a weather station to track wind direction. Doolan 2013 did not have full information of on/off time of wind farm to compare with measurements. Doolan 2013 only monitored one microphone position at a time.

Results

Doolan 2013 reported that measurements showed an increase in the overall mean Z (unweighted) and C-weighted sound level with annoyance rating. However no increase was observed in the mean A-weighted sound level. Levels within the 10-30 Hz band were observed to increase with annoyance rating.

Zajamsek 2013a reported all levels in the infrasonic and low-frequency region were well below the median hearing thresholds, and are thus unlikely to be audible.

Zajamsek 2013b reported that the noise levels show some increase with annoyance, but there was also close correlation of noise with local wind speed. Narrowband spectral density analysis results indicated infrasonic “tones”, only when the resident was not annoyed and local wind speed was low.

Zajamsek 2014 reported 14 figures of detailed results for Residence A and Residence B. During the measurement period at Residence A, 20 self-reported annoyance measurements were taken with three rated as “Very Annoyed”, six as “Moderately Annoyed”, seven as “Slightly Annoyed” and four as “Not Annoyed”. At Residence B, eight self-reported annoyance measurements were taken with one rated as “Very Annoyed”, two as “Moderately Annoyed”, two as “Slightly Annoyed” and three as “Not Annoyed”.

Conclusion

Doolan 2013 concluded: “that a test case, a home near a wind farm, was presented to demonstrate the use of the proposed technique. No link can be made between the noise data and the operation of the turbines; however, the data presented gives an insight into the type and level of noise experienced by residents and that they personally attribute to wind turbines. Additionally, significant level variation was detected in the noise signals; however, no trend with annoyance was observed.”

Zajamsek 2013a concluded: “1. The *Leq*, 2 min is well correlated with local wind speed. 2. Noise levels in the infrasound and low-frequency bands are well below the *ISO226-2003* median perception threshold, making them unlikely to be audible by a person with normal hearing. 3. Annoyance measurements do not directly correlate with the highest noise levels. 4. Some measurements show peaks in the infrasonic and low-frequency bands. In one case, these peaks appear to be revealed when local wind speed drops to a low value. 5. Without information concerning the operational state of the wind farm, the wind farm cannot be confirmed as the source of noise at low-frequency. 6. Since tonal components appear at very low and infrasound frequencies their direction of arrival could not be resolved by arrays whose low frequency limits were 50 Hz and 85 Hz respectively. According to the small data set collected in this preliminary study, no further conclusions can be drawn.”

Zajamsek 2013b concluded: “1. The *Leq,* 2 min is well-correlated with the local wind speed. 2. Noise levels in the infrasound and low-frequency bands (below 50 Hz) are well below the *ISO226-2003* median perception threshold, making them unlikely to be audible by a person with normal hearing. 3. Annoyance ratings do partially correlate with the high *Leq,* 2 min noise levels. 4. The resident was not annoyed when the local wind speed was low and its direction was scattered. 5. Some measurements show peaks in the infrasonic and low-frequency bands. In one case, these peaks are revealed when the local wind speed drops to a low value.”

Zajamsek 2014 concluded: “The noise level measured in both homes was found to be controlled by local wind speed more than any other factor. The highest noise levels were measured in the low frequency and infrasonic range however the levels at these frequencies were below the median hearing threshold making them unlikely to be audible by a person with normal hearing. Annoyance was found to be related to noise level and local wind speed in the home located 2.5 km from the wind farm. However, at the home located 8 km from the wind farm, annoyance was not controlled by noise level. In this case, time of day seemed to be a more important factor.

When the local wind speed was at a very low level, with correspondingly low background noise levels, tones at harmonics of the blade pass frequency were measured inside both homes. These tones were however below the threshold of hearing.”

EPA SA 2013	Design	Exposure	Outcome	Limitations
Noise				
Aim To investigate the concerns of the community regarding noise from the Waterloo Wind Farm, South Australia.	Report of a two-month investigation into the noise environment in an area where health concerns have been expressed by residents near a wind farm. Two main study components: (a) noise and weather monitoring and (b) community diary component. Commonalities between described noises amongst residents, specific environmental conditions that are related to disturbances, presence of low frequency and infrasound noise were explored across six residential sites. Report also reviewed current EPA wind farm noise guidelines. Location: Waterloo Wind Farm, South Australia.	Situated atop a north–south ridge, and stretching for 18 km, the wind farm comprises 37 Vestas V90 3 MW wind turbine generators (WTG), each having a hub-height of 80 m, with the entire site having a rated generation capacity 111 MW. Noise and weather monitoring at six sites 1.3 km to 7.6 km from the wind farm in question. Community diaries were kept by volunteer residents in the local area.	Noise and weather monitoring at six locations (houses) from 1.3 km to 7.6 km away from a wind farm. • Audio noise and infrasound (0.25 Hz to 20 Hz) were monitored (indoor and outdoor) at two of the houses. • Audio noise only (12.5 Hz to 20 Hz) was monitored (indoor and outdoor) at three of the houses. • Audio noise (12.5 Hz to 20 Hz) was measured (outdoor only) at one house. Six ten-minute shutdown periods took place in order to measure background noise levels. Operational and meteorological data were obtained from the wind farm operator. Weekly noise diaries were collected from residents; including information on perceived characteristics of noise, start time and end time.	Monitoring program was focused on homes of residents who had expressed concerns about noise. Noise diary data provided by residents of monitored homes, along with two other volunteering neighbouring residents (total of six sites with analysis of diaries and noise levels in Appendix C to Appendix H). Diaries often disagreed. Responder bias likely but triangulation with measured data is a rational way to analyse the diary data.

Results

Noise events attributable to the wind farm were periodically audible at four houses, but at very low levels, forming a minor component of the overall noise environment. No attributable noise events were found at the two remaining houses. Where detected, wind farm noise was within EPA noise guidelines for wind farms.

Specific wind farm operating and weather conditions generated more low frequency noise, and this was consistent with noise diary data collected from the community. Noise diary data reported a ‘rumbling’ noise effect at certain times which respondents attributed to the wind farm, however investigators could only detect this effect on amplification and could not attribute it to wind farm operations and at times it coincided with wind farm shutdown periods. Typically the effect was recorded under downwind conditions when the local background noise was low, notably at low local wind speeds. Background noise resulting from local winds and other noise sources was shown to contribute to increases in low frequency noise that were comparable with, or higher than, contributions from the wind farm.

A ’blade pass frequency‘ infrasound component was detected at levels significantly below the accepted audibility threshold (85 dB(G)) in the homes where infrasound was monitored.

Low frequency noise characters found in this study would not normally be audible to typical listeners, however sensitive residents in this quiet environment may perceive it and this could cause annoyance to some people if exposed for prolonged periods. This type of noise was identified at three residences when audio recordings were amplified.

Conclusion

Authors concluded “Analysis of acoustic data and audio records measured at the township and east sites did not show evidence for noise that may have been associated with wind farm operations.... Noise impact from the wind farm, where detectable, was found to comply with the conditions of the development of approval and the baseline criterion of 40 dB(A).”

Evans 2013	**Design**	**Exposure**	**Outcome**	**Limitations**
Noise				
Aim To compare measured infrasound (noise at frequencies lower than 20 Hz) and low frequency noise (noise from frequencies of 10 Hz to 160 Hz) levels between the measurement stages and to relevant	Noise monitoring survey in response to concerns raised by some community members. Indoor measurement of infrasound (< 20 Hz) and low frequency noise (10 Hz to 160 Hz) at two homes near a wind farm at pre-operational and operational time periods (1.8 km and 2.7 km from nearest turbine). Measurements of infrasound and low frequency noise were	A wind farm of 140 x 3 MW WTG monitored during wind farm’s pre-operational phase (Sept 2012), during full operation (March-April 2013) and at an intermediate time when 105 out of 140 WTGs were operational (Nov-Dec 2012). Infrasound and low frequency noise levels at three operating conditions: • No WTGs operating	Differences in infrasound and low frequency noise measurements compared during the three time periods described.	Two homes near the wind farm were monitored. Rationale for selection of these dwellings was not described in detail and recruitment of home owners was not described, however the rationale for the survey was that it was in response to concerns raised by some community members, therefore presumably the two sites were homes of concerned residents. Possible bias in selection of

<table>
<tr><td>assessment criteria.</td><td>compared with relevant Australian noise guidelines.
Location: Macarthur Wind Farm, Victoria.</td><td>- 105 operating WTGs
- 140 operating WTGs
Noise measurements included:
- Infrasound assessment
- Low frequency noise
- Linear sound pressure measurements</td><td></td><td>monitoring sites.</td></tr>
<tr><td colspan="5">Results
No differences in infrasound levels at both residences were observed during the differing measurement periods (taking into account variables such as wind direction), with almost all results below 85 dB(G) assessment criteria.
Low frequency noise measurements showed an increase in noise levels at 63 Hz and above during the operational stages (105 WTGs and 140 WTGs) at one of the residences. Of these increases seven ten-minute periods out of 23 nights of monitoring exceeded the criteria, although this was likely to be influenced by local wind noise.
Conclusion
Authors concluded “Overall, this assessment has demonstrated that infrasound and low frequency noise levels from [the wind farm] are compliant with relevant assessment criteria at the two nearby residences. No change in infrasound levels was identified relative to the pre-operational monitoring. An increase in low frequency noise levels at frequencies of 63 Hz and above was measured at each of the residences for particular conditions and may be a result of noise from [the wind farm]”.</td></tr>
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<table>
<tr><th>Møller 2011</th><th>Design</th><th>Exposure</th><th>Outcome</th><th>Limitations</th></tr>
<tr><td colspan="5"><i>Noise</i></td></tr>
<tr><td>Aim
To describe the spectrum of noise associated with large wind turbines and in particular the role of low frequency sound and infrasound.
As stated in the Introduction, “…the hypothesis that the spectrum moves toward lower</td><td>Accoustical noise survey conducted in Denmark. Noise spectrum assessment of wind turbines of different sizes. Differences in noise emissions of 48 small and large wind turbines were analysed.
A measurement of low frequency sound insulation to exterior sound across ten rooms in typical houses was also undertaken to assess the penetration of wind turbine noise.</td><td>Noise data from 48 WTGs were included. Noise from four large prototype turbines (> 2 MW) was measured. The effect of wind speed on noise was also measured. Previously collected noise measurement data from seven other similarly large turbines and 37 smaller turbines (< 2 MW) were obtained from the Danish EPA. All turbines were three-blade WTGs with the rotor to the upwind side of the tower.</td><td>Estimation of indoor sound penetration of homes in the vicinity of WTGs was made by discounting outdoor sound pressure levels to take into account the attenuation of noise by the house structure.</td><td>Problems with background noise limited the sound insulation evaluation of indoor spaces and the resultant statistical model was based on fewer measurements than planned.
Assessment of indoor sound insulation method was focused on house façades and did not include noise exposure via other noise paths (e.g. roof, back of house etc.) which would be exposed to WTG noise, especially relevant for</td></tr>
</table>

frequencies for increasing turbine size is investigated.”		Low-frequency noise penetration into indoor spaces was modelled based on sound insulation evaluation of ten rooms in five average Danish houses which were exposed to artificial noise via an outdoor loudspeaker.		low frequency sound. Assumptions made in the outdoor free-field sound pressure level calculations that could lead to highly variable low frequency sound predictions. Modelling assumes house windows closed, which limits generalisability to warmer climates. Assumptions in models may not apply in all atmospheric conditions (e.g. when there is a temperature inversion or low-level jets).

Results

Large wind turbines emitted more low frequency noise (2.3-3.6 MW) than small turbines (≤2 MW), which was statistically significant. The difference equates to a one-third octave difference in noise pitch of large vs small turbines. Therefore, as turbines become larger it is expected that more low frequency sound will be generated by wind turbine installations.

Due to air absorption, low frequency noise becomes more pronounced when outdoor sound pressure levels are taken into account (higher frequency sound is absorbed more than low frequencies). Indoor low frequency noise levels are influenced by sound insulation in the measured room, position of a room and turbine characteristics. Infrasound emitted by WTGs was found to be well below the threshold of hearing, even in immediate vicinity of WTGs where infrasound is imperceptible.

The minimum distance at which noise levels comply with a 35 dBA limit varies considerably between the large turbines, even when the turbines are relatively equal in size (2.3 MW to 3.6 MW). The distance varies from slightly over 600 m to more than 1200 m. It was found that the noise from WTG increases with wind speed, but levels out or even decreases above 7–8 m/sec.

Conclusion

Authors concluded that the spectrum of wind turbine noise moves down in frequency with increasing turbine size. The relative amount of low frequency noise is greater for large WTGs (2.3 MW to 3.6 MW) than for smaller WTGs (< 2 MW). Because distance attenuates higher frequencies more readily, low frequencies are more pronounced outdoors over distances relevant to neighbouring houses. Therefore the low frequency part of the spectrum plays an important role in the noise at nearby dwellings. The authors state that the turbines do emit infrasound (sound below 20 Hz), but levels are low when human sensitivity to these frequencies is accounted for. Even close to the turbines, the infrasonic sound pressure level is much below the normal hearing threshold, and infrasound is thus not considered as a problem with turbines of the investigated size and construction. The authors regard infrasound from WTGs of the kind investigated not to be problematic because the sound pressure levels of infrasound renders it imperceptible, even at close range. Under certain atmospheric conditions WTG noise may be more annoying, however more research is needed into this hypothesis.

van Renterghem 2013	**Design**	**Exposure**	**Outcome**	**Limitations**
Noise				
Aim (Not explicit in paper.) A listening experiment investigating annoyance, recognition and detection of WTG noise.	Investigated annoyance, recognition and detection of wind turbine noise through a listening experiment in which 50 participants with normal hearing ability were exposed to differing noise recordings. Noise recordings included an operating wind turbine, highway noise, local traffic noise and mixed recordings (i.e. wind turbine noise with local traffic noise).	Part 1 involved samples being played during a quiet leisure activity. Part 2 asked participants to identify the sample containing wind turbine noise in a paired comparison test. Participants were asked to rate their annoyance levels for the differing noise exposure and to identify the types of noise they believe were included in the recordings (blinded to the purpose of the study during these measurements). Participants were then exposed to the mixed recording and asked to detect the wind turbine sound. Sound recordings of a 1.8 MW wind turbine operating at 22 rpm, highway noise and local road traffic noise (unmixed and mixed). Recordings were adjusted to L_{Aeq} 40 dB(A) to simulate indoor sound pressure levels.	Participants were asked to rate their annoyance after exposure to six audio recordings at 7.5 minutes each. Recognition responses to the six recordings and detection responses to the mixed recordings (wind turbine noise with other noise). A short questionnaire assessed participant attitude in relation to renewable energy.	Measuring annoyance levels using a short exposure time (7.5 minutes per recording) may not provide a clear indication of the prolonged exposure that residents experience. Small and non-representative sample and the selection of participants was not described. The test group could be categorised as having a positive to neutral attitude in relation to renewable energy.
Results Under the conditions of Part 1, pure wind turbine noise gave very similar annoyance rating as unmixed highway noise at the same equivalent level, while annoyance by local traffic noise was significantly higher. The detection limit of wind turbine noise in the presence of highway noise was estimated to be as low as a signal to noise ratio of -23 dBA. The larger the signal-to-noise ratio, the larger the fraction of the participants that were able to identify the sample containing the wind turbine noise. When mixed with local road traffic, such a				

detection limit could not be determined. The findings support that noticing the sound could be an important aspect of wind turbine annoyance at the low equivalent levels typically observed indoors in practice.

Participants recorded a similar annoyance level between highway noise only and pure wind turbine noise. Significant differences were observed between the annoyance ratings to local road traffic compared with wind turbine noise and highway noise, with local road traffic annoyance levels the highest.

Conclusion

Authors concluded that this experiment supports previous observations that retrospective annoyance for WTG noise is greater than for highway noise at an equivalent noise level and that this difference is mediated by higher perception of noise level, emotional and/or cognitive processes. It was also found that traffic noise and WTG noise were perceived similarly when the noise source was not known beforehand, however in focused listening, WTG noise is sufficiently distinctive to allow detection even at low signal-to-noise ratios. Therefore, the authors concluded that focusing, triggered by more general knowledge of the presence of wind turbines, could increase annoyance. Some individuals were shown to recognise more readily WTG noise, even if its presence was not revealed beforehand.

Schiff 2013	**Design**	**Exposure**	**Outcome**	**Limitations**
Noise				
Aim To increase the understanding of potential noise issues related to industrial wind turbine operation in New York State, by examining the outcome of a recent wind project.	Environmental noise survey of five sites, 219 m to 663 m from operating 1.5 MW WTGs in a large wind farm project and two control sites (> 4.6 km removed). Each site was monitored for four days in summer, winter and autumn. Infrasound and low-frequency sound were also evaluated, wind conditions permitting.	Wind farm of 84, 1.5 MW WTGs. Outdoor noise measured on rural residential land parcels as far from buildings and roads as practicable within the selected land parcel. In some cases this resulted in monitoring location being closer to the nearest WTG than the dwelling on the land parcel in question. Meteorological data (weather, wind speed, wind direction, and temperature) were logged over concurrent periods at one of the central receptor locations.	n/a, environmental noise survey.	Only five measurement locations. One control site's data were discarded for summer and autumn monitoring campaigns. Therefore only winter monitoring had both control locations. Selection of residences for monitoring was not described. Justification of the 4.6 km distance for control residences was not provided. Indoor monitoring was not undertaken. Siting of outdoor monitoring (away from dwellings, sometimes closer to WTG than dwelling) may not accurately represent real human exposure. Sizes of land parcels in question were not defined, therefore the

				distances involved were not clear.

Results

Certain monitoring locations may have slightly exceeded 50 dBA, the local limit for wind turbine noise, though the assumed conditions associated with the standard may not have been exactly replicated in the study.

Measured results were within +/- 2 dB of a pre-development study model on an overall long-term basis, though individual measurements in the study were as high as +/- 5 dB of pre-development model. This would indicate that noise exposure could vary by up to 5 dB compared to model estimates.

Noise exposure was consistent between the autumn and winter campaigns, but overall A-weighted and low frequency noise was slightly lower during the summer campaign, suggesting that sound propagation differs depending on the season.

Conclusion

Authors concluded "measured sound levels at most locations exceeded the corresponding background location sound level by substantial and audible margins especially in moderate to high winds." Measured ground level wind speed tended to be marginally lower than that extrapolated from the 10 m wind mast, indicating that ground-level masking of turbine noise may sometimes be less than expected. Certain monitor locations may have slightly exceeded the 50 dBA local limit for wind power noise at the residence building itself. Measured background noise at an individual site was up to 5 dB lower than the pre-development survey, which amalgamated six different sites into one data set. Finally, the measured results were within a ± 2 dB margin of the pre-development study model on an overall long term basis, but for each individual measurement campaign this margin was as high as ± 5 dB.

Qibai 2004	**Design**	**Exposure**	**Outcome**	**Limitations**
Infrasound				
Aim To study the physiological and psychological effects of infrasound on persons.	Laboratory study. The physiological and psychological impact of exposure to infrasound was measured in ten university students (four female, four male; aged 22-28).	Ten participants were split into two exposure groups (A & B) with two females and three males per group. Group A was exposed to infrasound of 4.10 Hz at 120 dB for one hour and Group B was exposed to 2.14 Hz at 110 dB for one hour.	Blood pressure and heart rate were measured three times at two-minute intervals before exposure and after one hour of exposure. Subjective feelings and reactions were measured using a short questionnaire after exposure.	Small sample drawn from university student population which is not representative of the general population. Representativeness and generalisability questionable. Lack of baseline or pre-exposure questionnaire. Lack of a validated questionnaire instrument.

Results

No results which provide information about exposure to WTG outputs.

Physiological and psychological effects of infrasound appeared as changes in heart rate, blood pressure and subjective reactions. All participants reported feeling uncomfortable during exposure. Eight of the ten participants compared the feeling during exposure to travelling in a vehicle or train and nine of ten reported pressure in the ears. For all participants from Group A and B, at least one change of more than 10% was observed in at least one measurement (systolic pressure, diastolic pressure, heart rate). Group A showed an increase in systolic and diastolic pressure in four of the five participants. Heart rate also increased for four of the five participants, with one participant showing no change. Group B showed an increase in systolic and diastolic pressure for all participants. Heart rate also increased for four of the five participants. No major differences were observed between the two exposure groups.

Conclusion

Authors concluded "Different individuals have different responses to infrasound and the change ratio of blood pressure and heart rate are also different. By comparing physiological and psychological effects of infrasound on persons in two different infrasound conditions, we find that there are not obvious differences."

No conclusions relevant to exposure to WTGs.

Styles 2005	**Design**	**Exposure**	**Outcome**	**Limitations**
Infrasound				
Aim To identify the characteristic frequencies and mode of propagation of seismic vibrations from wind turbines and develop a model for the integrated seismic vibration at the Eskdalemuir seismological array facility which will be created by any distribution of wind farms.	Measurement of seismic and infrasound disturbances in vicinity of several Scottish wind farms in order to model and estimate the likely impact of a proposed large wind farm on the nearby British Geological Survey (BGS) seismological array.	Measurements were made by sensitive seismometers at 100 m, 50 m and 20 m. LFN was measured with digital seismographs with a bandwidth of 0.2 Hz to 64 Hz and acoustic noise was measured around a wind turbine.	To what extent would proposed wind farms be expected to transmit vibration into the ground such that would interrupt the operations of the nearby seismological array.	No limitations, other than possible uncertainty over applicability to other locations.

Results

The researchers were able to detect low-frequency sound waves at considerable distances away from a wind farm under the right atmospheric conditions with highly sensitive seismometers.

The authors recommended exclusion distances around nearby BGS seismological array based on the probability of interference from the transmission of vibration from wind turbines to the ground. The vibration levels about which this study was concerned were below the limit of human sensation because this study was not concerned with human effects, but with possible effects on the highly sensitive Eskdalemuir seismological array used by the British Ministry of Defence for international detection of nuclear test explosions.

Conclusion

Authors concluded "By considering the present ambient background experienced at the monitoring site it has been possible to set a noise budget which is permissible at Eskdalemuir without compromising its detection capabilities. … [the measurements] have demonstrated that at least 1.6 GW of planned capacity can be installed and have developed software tools which allow the Ministry of Defence and planners to assess what further capacity can be developed against criteria established by this study".

Tickell 2012	**Design**	**Exposure**	**Outcome**	**Limitations**
Infrasound				
Aim To review recent papers describing low-frequency, infrasound and amplitude-modulation noise from wind turbines, and whether low-frequency and infrasound from wind farms is a real measureable issue.	A narrative review of recent publications.	No noise measurements collected. Sound levels reported from various reviewed studies.	For low frequency noise from wind turbines, a comparison of findings from published studies. For modulation sound levels from wind turbines, sound levels at different distances from five wind turbines from a study by Miyazaki 2011.	Non-systematic review, completeness of coverage and representativeness of cited papers is questionable.

Results

Figure 1: Comparison of low frequency hearing thresholds with Wind Turbine Sound Levels at low frequencies from five studies. The figure showed that for the frequency range below 25 Hz, which includes the infrasonic range, the sound levels from the five wind turbines were less than the threshold of hearing – for frequencies less than 20 Hz, this difference was at least 10 dB and increased with reducing frequency. The measurement distances ranged from 44 m to 77 m. Figure 2: Sound levels of reference distances from five wind turbines from a study published in 1990, showed that the rotor trailing edge was a source of high noise emission. Figure 3: Results of predicted sound levels at increasing distances from a 2.5 MW wind turbine, for overall sound levels and modulation depth, indicating that while the overall sound pressure level decreased with distance, the modulation depth was consistent with distance.

Conclusion

Author agreed with findings of a reference that an objective external sound level for residential receivers should be 60 dB(C) for night-time. Author suggested that amplitude modulation should be considered as an addition to predicted overall sound level at receiver locations for comparisons with environmental noise quality objectives.

Turnbull 2012	**Design**	**Exposure**	**Outcome**	**Limitations**
Infrasound				
Aim Reports a new acoustical methodology for measuring infrasound.	Methodological evaluation of a monitoring method for infrasound (specifically a means of minimising influence of wind on microphone). Measurements within a test chamber below the ground surface were used to compare infrasound at two South Australian wind farms (Clements Gap Wind Farm and Cape Bridgewater Wind Farm) and in the vicinity of a beach, coastal cliff, city and power station, using the same measurement methodology.	Infrasound from wind farms and other sources. Environmental noise measured against the infrasound audibility threshold limit of 85 dB(G).	Measured levels of infrasound from wind turbines and other natural sources.	Modelling is lacking. All measurements reported in Table 2 for various sources are at different distances, making comparisons unclear. Limited reporting of variations in infrasound levels due to different atmospheric conditions.
Results Infrasound levels inside the underground chamber were the same as those of the signal generator. Levels of infrasound were similar at a beach, in the vicinity of a coastal cliff and close to wind turbines. The proposed measurement method used in the study illustrates that the infrasound generated from wind turbines is well below the audibility threshold level. The reduction of signal strength during transmission of 6 dB per ‘doubling distance’ from a turbine was adequately demonstrated. The infrasound noise level generated by wind turbines is similar to urban and costal environments and other engineered noise sources. The measured levels of infrasound from the wind turbines and all other natural and engineered sources were well below the 85 dB(G) threshold of audibility. The measured levels included a significant contribution of infrasound from the wind farm at 100 m, but at a distance of 200 m from the wind farm the infrasound from the other sources was at similar levels, e.g. 74 dB(G) at 350 m from a gas-fired power station and 63 dB(G) at 200 m from the Cape Bridgewater Wind Farm. **Conclusion** Authors concluded “The measured level of infrasound within the wind farms is well below the audibility threshold and similar to that of urban and coastal environments and near other engineered noise sources… The method shows that for wind turbines, the level of infrasound is well below the audibility threshold of 85 dB(G). An attenuation rate of 6 dB per doubling of distance from a single turbine. Infrasound is prevalent in urban and coastal environments at similar levels to the level of infrasound measured close to a wind turbine”.				

Walker 2012	**Design**	**Exposure**	**Outcome**	**Limitations**
Infrasound				
Schomer 2013 **Aim** To present information from an investigation of infrasound and low frequency noise performed at Shirley wind farm in Brown county Wisconsin in December 2012. Schomer 2013 To propose the hypothesis that very low frequency wind turbine noise emissions may induce motion sickness in susceptible persons, as the same inner ear organs may be central to both conditions.	An environmental noise monitoring survey undertaken for litigation purposes. Symptoms were also collected and this was cross-sectional. Low frequency noise (LFN) and infrasound measurements at three residences (indoor and outdoor) in varying proximity to wind turbines (0.3 km to 2.1 km). Data were collected by five investigators from four firms of consultants. Schomer 2013 A survey among 50 (of 275) people residing within 5000 feet of the closest wind farm in Shirley, Wisconsin who described adverse effects after introduction of the wind turbines. Selection criteria further restricted to a sub-subset of two (out of five) people exhibiting motion sickness symptoms who meet the following criteria: i) about half or more of their symptoms must be motion sickness symptoms; ii) the overall symptoms must be severe enough that the people abandon their homes (or equivalent); iii) the motion sickness symptoms must include nausea; and iv) the motion sickness symptoms must play a	Wind farm consisting of eight wind turbines. Measurements made at three homes abandoned by owners due to health complaints attributed WTG health effects. Primary measurements were made at the three abandoned residences on consecutive days by four consulting firms. Sound pressure was measured using a custom designed multi-channel data acquisition system in the time domain at a sampling rate of 4000/sec where all signals were collected under the same clock. At each residence, a multi-channel recorder was connected to an outside wind-speed anemometer and a microphone; others channels of the recorder were connected to microphones inside each residence that were situated in various rooms including basements, living or great rooms, office or study, kitchens and bedrooms (observations were based upon coherence calculations for indoor and outdoor microphones). Data collected at Residence 2	Indoor and outdoor sound pressure measurements and spectral data were taken at three unoccupied homes near wind turbines in a Wisconsin wind farm. Investigators' observations of perceived low frequency noise and infrasound at the test locations. Investigators' observations of any health effects (own) during and after the 3-4 day monitoring periods. Detection of infrasonic pressure modulations from the wind turbine to the residence. Reports on any health issues experienced by neighbours (nausea, dizziness and headache).	Focused on a single wind farm with a history of high levels of community dissatisfaction and complaint. Measurements taken from homes which were abandoned because of concerns or complaints attributed to WTGs. No measurements of occupied homes. The decision was made not to measure acoustic data at a control home far away from the wind farm site, despite its intention in the original survey design. Emphasis on the consultants' self-reported perception of noise and health symptoms during the period of monitoring. Limited due to small sample size and lack of blinding. Schomer 2013 Small sample size and lack of blinding. Unlikely to be representative and response and recall biases likely. Recruitment rate low and likely subject to recruitment bias. Noise data from only one residence were used in the analyses, as that residence was "tested during a time when significant power was being generated", whereas the wind

	prominent role in the subject's overall response to wind turbine noise. (The following reported effects were tested: whether effects were similar from one space to another, were independent of the rotor, and were not related to audible sound.)	were measured with 58% of turbine power, but < 58% during measurement periods at Residence 1 and Residence 3 (so only data from Residence 2 was used). Neighbour reports and physiological effects including nausea, dizziness and headache were documented.		turbine operator "was not generating much power during the measurements" at the other two residences. Much of report is speculative in nature, discussing hypotheses and possible mechanisms.

Results

Walker 2012 Infrasound attributable to WTGs was detected above background at the residence closest to the nearest turbine.

One of the investigators (R Rand) incurred symptoms during the survey and on this basis, suggested that nauseogenicity is a factor at Shirley. The other four investigators did not report any symptoms. Infrasound was measured at very low frequencies (0.7 Hz) but was inaudible.

Schomer 2013 Most residents do not hear WTG sound and annoyance reportedly not present. Physical symptoms reported similar to motion sickness among some respondents (10%).

Conclusion

Walker 2012 concluded that analysis of measurements showed that only very low frequencies are detectable throughout the houses and that they are related to the blade passing frequency of the nearby wind turbines.

Schomer 2013 concluded that respondents reporting symptoms of motion sickness (apparently without noise annoyance) also report susceptibility to motion sickness. Therefore, the authors concluded that sensitivity to motion sickness and sensitivity to WTG emissions are likely related among a small fraction of those exposed.

Maschke 2007	**Design**	**Exposure**	**Outcome**	**Limitations**
Annoyance				
Aim Using data from the LARES survey, neighbour noise annoyance was surveyed as an adverse housing condition and its	Analysis of cross-sectional survey data from a WHO European housing and health survey (LARES Survey). LARES collected data in eight European cities to evaluate the effects of housing conditions on health.	Noise exposure not measured; 'noise annoyance' rather than actual noise was the independent variable of interest and this was collected by questionnaire. Neighbour noise was assessed by four items: neighbour flat noise; stairwell noise; children playing in	Housing and neighbourhood satisfaction were collected by questionnaire completed by one household member. Health data were collected by questionnaire from each household member. Self-reported medical diagnoses of hypertension, depression and	Cross-sectional design limits ability to determine causality. Reverse-causality is plausible. Dependent and independent variable data both self-reported. Over-reporting of health effects by noise-annoyed respondents would lead to over-estimation of risk

relation to reported medically diagnosed illnesses was evaluated.	The present paper reports analysis of self-reported annoyance from neighbour noise over the previous 12 months and self-report of 15 different health conditions over the previous 12 months.	building; noises within dwelling. Total score was categorised as no annoyance, moderate, severe.	migraine.	estimates. Reverse causality is also possible if poor health is associated with poorer noise tolerance and/or higher duration of exposure as a result of increased time at home. Unclear how health data were collected for children but likely by proxy which would be subject to proxy response bias, particularly problematic if the proxy respondents were also respondents in their own right, which seems likely.

Results

For adults, a dose-effect relationship was observed between annoyance induced by neighbours and self-reported hypertension (p = 0.007). The p-value following adjustment for risk factors was 0.018. Self-reported depression was greater with higher annoyance by neighbour noise, suggesting a dose response relationship (p = 0.005; p = 0.041 adjusted for socio-economic state, risk factors, general environment and housing factors). Self-reported migraine was also higher (p = 0.001; p = 0.022 adjusted for risk factors, general environment and housing factors). A significant increased risk of self-reported arthritis was recorded for elderly people who indicated moderate chronic annoyance by neighbour noise, but this trend was not significant for severe neighbour noise annoyance. Increased risk of reported bronchitis in children was associated with chronic noise annoyance (p = 0.002; p = 0.004 following adjustment for socio-economic state).

Conclusion

Authors concluded: "The results of the survey confirmed the thesis that neighbour noise effects health via long lasting severe annoyance. Neighbour noise induced annoyance is therefore a highly underestimated risk factor for healthy housing." Authors recommended that chronic severe annoyance induced by neighbour noise be classified as a serious health risk for adults. Likewise, the authors recommended that children be classified as a risk group. Epidemiological confirmation is needed of neighbour noise affecting health via long lasting severe annoyance, for both cardiovascular and respiratory symptoms.

McCallum 2014	**Design**	**Exposure**	**Outcome**	**Limitations**
Electromagnetic Field (EMF)				
Aim To characterise EMF in the vicinity of an active wind farm in Ontario, to address the heightened anxiety by some around electromagnetic field, wind turbines and human health.	Environmental monitoring survey of EMF in vicinity of wind turbines.	EMF measured in the proximity of 15 vestas 1.8 MW wind turbines, two substations, both buried and overhead collector and transmission lines and nearby homes.	EMF measurements were collected under three operational scenarios to characterise potential EMF exposure. Operational scenarios were high wind (generating power), low wind (drawing power from the grid but not generating power) and shut off (not generating power).	Static monitoring rather than personal monitoring may not reflect actual personal exposure.

Results

Limited levels of EMF measured around the wind farm suggested that human exposure to EMF from wind turbines is insignificant in comparison to common household exposures.

Location of exposure	**mG**
Background levels of EMF (shut off scenario)	0.2 mG to 0.3 mG
*Base of turbines (at high wind and low wind)	mean = 0.9 mG; n = 11
Buried collector lines (1 m above)	≤ 0.3 mG
Beneath overhead transmission lines	16.5 mG and 46 mG
**Nearby homes (outside – 500 m away)	≤ 0.4mG

* all diminished with distance ** sources did not appear to influence level

EMF exposure was not unique to the wind farm, exposure was lower than common electrical devices (common household items) and was below human health regulatory guidelines.

Conclusion

Authors concluded "The results suggest that there is nothing unique to wind farms with respect to EMF exposure. Magnetic field levels in the vicinity of wind turbines were lower than those produced by many common household electrical devices and well below any existing regulatory guidelines with respect to human health".

Mechanistic Evidence

Chapman 2013	**Design**	**Exposure**	**Outcome**	**Limitations**
Mechanistic Evidence				
Aim To test four hypotheses relevant to psychogenic explanations of the variable timing and distribution of health and noise complaints about wind farms (WF) in Australia.	Historical audit. Information on the commencement of turbine operation, number of turbines operating, average turbine size and the megawatt (MW) capacity of each wind farm was located from public sources, such as wind farm websites. Information about complainants, including date first complaint occurred, adverse effects on health and sleep or annoyance of turbine sound among residents in the vicinity of operating wind farms, and occurrence of anti-WF activity in the local area were requested from the wind farm owners. Additional information was collected from: 1. Submissions made to three government enquiries on wind farms. 2. Daily media monitoring records supplied to the Clean Energy Council by a commercial monitoring company from August 2011 to January 2013. 3. Personal correspondence to the	Companies provided estimates of the number of residents currently living within 5 km of each wind farm – either estimates of the number of individuals or the number of houses.	Proportion of WFs with complaints. Proportion of residents in vicinity of operating WFs who complained. Proportion of WFs with a history of complaints consistent with claims that turbines cause acute effects. Date/Period of first complaints.	Population estimates included children, who would be unlikely to complain to a regulatory body regarding wind farms. The primary source of information on complaints was from the WF operators. Estimates of resident numbers relied in some cases on estimates made using Google Earth images and so precise numbers of residents living within the 5 km boundary were not available.

<table>
<tr><td></td><td>authors about complainants who had complained via a legal case.</td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Results
1. Hypothesis 1 – Many WFs would have no history of complaints: 33 of 51 WFs (18/34 of larger wind farms and 15/17 of small farms), with an estimated 21,633 residents living within 5 km of turbines, and had operated for a cumulative total of 267 years, had never been subject to health or noise complaints. Small total capacity farms were less likely to have complainants (88% vs 53%, $\chi^2 = 6.18$, 1df, $p = 0.013$). 18 WFs (35.3%) received at least one complaint since operation started, 16 of which were larger WF (≥ 10 MW). Distribution of WFs which have ever received complaints is highly variable across Australia (there have been no complaints in TAS or WA).
2. Hypothesis 2 – There would be a small proportion of complaining residents: 129 out of 32,789 individuals residing within 5 km of WFs complained about noise or health effects. 94 (of 129) were from residents living near 6 WFs. 124 (of 129) represented 1 in 100 of the surrounding 12,366 residents living near large WFs (> 1 MW).
3. Hypothesis 3 – Few WFs would have any history of complaints consistent with claims that turbines cause acute effects: six WFs saw complaints commence at times ranging from two months to 13.5 years after turbine operation. 12 WFs had either on-going complaints continue from before the WFs commenced operation or within the first month.
4. Hypothesis 4 – Most complaints would date from 2009 or later, when anti-WF groups began to publicise alleged health effects. 69% of WFs began operating prior to 2009, 90% of complaints were received after this date. 15 of 18 WFs (83%) that have seen complainants have experienced local opposition from anti-WF groups.
Conclusion
Authors concluded “the historical and geographical variations in complaints are consistent with psychogenic hypotheses that expressed health problems are communicated diseases with nocebo effects likely to play an important role in the aetiology of complaints”.</td></tr>
</table>

<table>
<tr><th>Crichton 2014</th><th>Design</th><th>Exposure</th><th>Outcome</th><th>Limitations</th></tr>
<tr><td colspan="5"><i>Mechanistic Evidence</i></td></tr>
<tr><td>Aim
To test the following hypotheses: (a) that high-expectancy would be associated with increased symptom reporting (number and intensity), (b) that high expectancy participants would be more likely to report</td><td>A sham controlled double blind provocation study in which 54 university students (34 female, 20 male) were randomly assigned to groups of high expectancy and low expectancy that infrasound causes specific symptoms.</td><td>Participants from each group were shown the relevant expectancy video – high expectancy video (of symptomatic experiences due to wind farm) or low expectancy video (of scientific position on lack of symptoms from infrasound) and then exposed in a standards-compliant listening room to ten minutes of infrasound and ten minutes of sham infrasound (no sound) in a counterbalanced design. Participants were told</td><td>Subjects were asked about health effects of wind turbine sound at baseline and after video viewing.
Self-reported physical symptoms, 12 specified to be typical of infrasound and 12 less typical, were elicited before and during each ten-minute exposure session.
A total symptom score was calculated for each rating period.
Blood pressure and heart rate were monitored.</td><td>Minimal information on the spectrum and amplitude of the auditory stimulus.
Small sample drawn from university student population which is not representative of the general population.
Unclear whether blood pressure and heart rate were monitored pre-exposure to determine whether there was variation between the randomly assigned</td></tr>
</table>

symptoms described as typical of infrasound exposure and (c) that there would be no effect of actual infrasound exposure on reported symptoms.		both sessions were infrasound and experimenter was blinded to the order of exposure. Sound transmitted during exposure sessions 40 dB at 5 Hz (no other information given).		groups. Comparatively low level of exposure to infrasound given some levels measured in residence close to wind farms – e.g. 60 dB or higher.
Results When given information about the expected physiological effect of infrasound reported symptoms, participants' self-reported symptoms aligned with that information, during exposure to both infrasound and sham infrasound. Number and intensity of symptoms in the high intensity group increased from the baseline level during both real and sham infrasound whereas there was little or no increase in either during exposure, whether real or sham, in the low expectancy group. A mixed model ANCOVA found a significant main effect of expectancy group on both symptom change ($p < 0.01$) and symptom intensity ($p < 0.01$). The high expectancy group expressed greater concern regarding the health effects of sound generated by wind turbines than the low expectancy group $p < 0.001$. Heart rate and blood pressure did not change materially during exposure to infrasound in either expectancy group ($p = 0.09$ to $p = 0.9$). **Conclusion** Authors concluded that "Results suggest psychological expectations could explain the link between wind turbine exposure and health complaints".				

Crichton 2013	**Design**	**Exposure**	**Outcome**	**Limitations**
Mechanistic Evidence				
Aim To investigate whether positive expectations about infrasound can produce a reduction in reported symptoms and health in response to exposure to wind farm noise.	An experimental study in which 60 undergraduate students (39 female, 21 male) were randomly assigned to positive or negative expectation groups.	Participants from each group were shown TV footage of either negative health effects associated with infrasound produced by wind turbines or therapeutic effects associated with infrasound. Participants from each group were then exposed to audible wind farm sound (43 dB) and infrasound (9 Hz, 50.4 dB) and audible wind farm sound (43 dB) for two seven-minute listening sessions.	Participants' symptoms and mood were assessed using a seven-point Likert scale. This questionnaire was filled in at baseline and during each exposure period.	Self-reported outcomes. Small sample drawn from university student population which is not representative of the general population.

Results

During exposure to audible wind farm sound and infrasound, self-reported symptoms and mood were strongly influenced by the type of expectations. Negative expectation participants experienced a significant increase in symptoms and a significant deterioration in mood, while positive expectation participants reported a significant decrease in symptoms and significant improvement in mood.

Evaluation of perceived health impacts of infrasound exposure showed 90% of the positive expectation group reported an improvement in physical symptoms after the listening sessions had concluded compared to 10% of the negative group ($p < 0.001$). Consistently, 77% of the negative expectation group reported a worsening of symptoms during exposure, compared to 10% of the positive group ($p < 0.001$).

Conclusion

Authors concluded "that expectations can influence symptom and mood reports in both positive and negative directions. The results suggest that if expectations about infrasound are framed in more neutral or benign ways, then it is likely reports of symptoms or negative effects could be nullified".

Kelley 1987	**Design**	**Exposure**	**Outcome**	**Limitations**
Mechanistic Evidence				
Aim To identify metrics or descriptors for low frequency community annoyance for wind turbine noise applications.	Experimental study. Seven volunteer evaluators took part in the experiment. The group consisted of three women and four men aged from early twenties to early sixties.	Low frequency noise (LFN) generated by sub-woofer speaker in room next to a second room used as a listening room by the evaluators.	Comparison of noise annoyance ratings for six different metrics for low frequency noise. Annoyance results for the following: • A-weighted noise level • C-weighted noise level • G_1 (Less than 20 Hz) • G_2 (Less than 20 Hz) • LSL which reflects three LFN influences • LSPL which is similar to LSL	Small study with only seven participants. Participant selection not described and representativeness unclear. Generalisability to general population may be limited. Final recommendation involves complicated procedure for community annoyance evaluation.

Results

Establishment of an interior noise annoyance scale. This was achieved by using the annoyance of the evaluators and described in Table 4. Table 4 results indicate that LSL and C metrics were ranked equal highest as efficiency metrics, with LSPL and G_1 equal second, G_2 third and A-weighted ranked 4th.

Table 5. INTERIOR LF ANNOYANCE-LEVEL CRITERIA EMPLOYING THE LSL AND C METRICS

	Threshold Annoyance		Unacceptable Perception Threshold		Annoyance Stimuli	
	LSL	C	LSL	C	LSL	C
Class	(dB)		(dB)		(dB)	
Nonimpulsive, periodic random	58	68	65	75	68	77
Periodic impulsive source	53	63	57	67	60	68
Random periodic source	59	67	68	76	70	78

Conclusion

The authors describe a methodology for describing worst-case low frequency wind turbine noise based on the LSL and C metrics. The derived levels can then be compared with Table 5 (above) to assess the interior annoyance potential.

Ruotolo 2012	**Design**	**Exposure**	**Outcome**	**Limitations**
Mechanistic Evidence				
Aim To assess impact of a wind farm on individuals by means of a virtual audio-visual methodology to stimulate biologically plausible individual-environment interactions. To	Laboratory trial (unblinded). 93 university students aged 19-34 years (51 females). There were no control subjects.	Subjects were exposed to recorded noise and/or video representing a wind farm at 20 m, 100 m, 250 m and 600 m. Noise was recorded at an Italian wind farm. Visual stimuli were reproduced using a 3D graphic tool to represent WTGs at these distances and a control condition representing the same landscape without WTGs. There were three	While exposed to noise and/or video conditions, subjects performed tasks assessing verbal fluency, short-term verbal memory, counting backwards and distance estimations (egocentric and allocentric). After exposure, participants were asked to report their degree of visual and noise annoyance using standard assessment methods	Subjects recruited from university student population, not representative of general population. Few details about subject characteristics reported. Plausible confounders such as socio-economic status or health status were not controlled. Given that experimental subjects were university students, generalisability to people living

disentangle the effects of auditory and visual components on cognitive performances and subjective evaluations, unimodal (audio or visual) and bimodal (audio-visual) conditions were compared).		experimental conditions: (1) audio + video, (2) audio only, (3) video only.	(ISO/TS15666).	near wind farms is questionable. Generalisability to Australian context is also questionable. Noise levels (dBA) and power output of WTGs in question were not provided so comparisons with other studies are problematic. Generalisability of annoyance resulting from brief exposure in a laboratory context is unlikely to be generalisable to annoyance which may result from long-term residential exposure.
Results Results indicated that proximity to wind farm noise was associated with poorer performance in executive control (backwards counting) and semantic memory (verbal fluency) tasks, consistent with previous similar research on different types of environmental noise (e.g. commuter train noise). The performance in executive control improved as distance from the WF increased ($p = 0.009$). Semantic memory was influenced by distance from the WF ($p < 0.001$) as well as distance and noise sensitivity ($p < 0.001$). Short-term verbal memory was not influenced by the exposures. Presence of a visual representation of a wind farm may have a negative effect on performance of certain cognitive tasks but a mitigating effect on perceived noise annoyance. **Conclusion** Authors concluded that the mitigating effect of visual cues on perception of annoyance underscores the importance of complex modelling when undertaking environmental impact assessments in order to simulate as closely as possible the multisensory human-environment interaction, for which Immersive Virtual Reality may be a useful tool.				

Taylor 2013b	**Design**	**Exposure**	**Outcome**	**Limitations**
Mechanistic Evidence				
Aim To present the findings of a study of measured noise from small wind installations and the effect of individual	A cross-sectional environmental noise and opinion survey of residents living near micro and small wind turbine installations. 138 residents (age ranging from 20-95; 74 male, 62 female; two unknown) living within 500 m	A computer model together with L_{Aeq} noise measurements, were used to generate sound maps in the vicinity of 12 micro (0.6 kW) and small (5 kW) wind turbine installations. Measures of frequency spectra and indication	Participants were asked about perceived noise intrusion, attitudes towards wind power, mood, general health, personality traits and demographic details via the postal questionnaire.	Postal survey, potential selection bias (analysis by occupational groups showed no significant differences between occupational groups). Authors reported that demographic characteristics of participants were checked and

personality traits on noise perception.	of one of 12 micro or small wind turbines participated in the study via postal questionnaire. 1327 households were contacted (response rate of 10.86%).	of key frequencies were documented.		found to be representative of the relevant wider populations, however the results were not described. The study is open to retrospective and recall biases. Cross-sectional study, limited ability to determine causality.
Results The survey showed that the most commonly perceived noises are 'swooshing' and 'humming', the presence of which may be inferred from the measured frequency spectra. Negative attitude to wind turbines was associated with increased perception of noise (p = 0.001) from nearby turbines and perception of more noise was associated with increased levels of general symptoms reported (p = 0.014). It could not be determined if noise perception causes negative attitude or if negative attitude enhances noise perception. Respondents who could see a turbine from their dwelling did not have a significantly more negative attitude to wind turbines (p = 0.993). Individuals' personalities influenced attitudes towards wind turbines, noise perception and symptom reporting. At one of the installations, sound levels were higher at all frequencies when the turbines were switched on. There was a peak in the turbine spectrum at around 160-500 Hz, which was higher than the blade pass frequency mechanism. Therefore, the authors concluded that the peak was due to mechanical noise at the turbine hub as a result of electromechanical equipment. At the highest frequencies, a large difference was observed between the two sets of data with the turbines increasing the LAeq by almost 20 dB(A) at 10 kHz (reference sound pressure value 2 x 10^{-5} Pa for all values). **Conclusion** Authors concluded "it has been found that an individual's level of positive and negative affectivity best explain the variance in attitude to wind turbines and noise perception. It has also been demonstrated that attitude to wind turbines has a significant effect on noise perception and that noise perception has a significant effect on symptom reporting."				

Parallel Evidence

Chao 2012	**Design**	**Exposure**	**Outcome**	**Limitations**
Parallel Evidence				
Aim To clarify health effects in maintenance	Cross-sectional study. 213 Taiwanese aerospace maintenance workers divided into three groups according to	Each group exposed to different noise exposure. LFN (n = 64) or General Noise (GN) (n = 89) or no Noise (control group) (n = 60).	Evaluation of working environment: determination of source noise. Noise exposure of LFN group was	Noise measurements in the work-areas are poor, only spot measurements and not noise dosimetry. The audiometry is

<table>
<tr>
<td>workers exposed to low frequency and/or general noises.
To understand the relationship between the variations of workers' echocardiographic E/A ratio and LFN.</td>
<td>occupational noise exposure.</td>
<td>Noise exposure was assessed by spot measurements in the workplace.</td>
<td>98 dB(A) compared to the GN group of 92 dB(A). In the low frequency range (20-500 Hz) the LFN group were exposed to 96 dB(Lin) compared to less than 80 dB(Lin) for the GN group.
Biological monitoring: hearing evaluation; electrocardiographic E/A ratio.</td>
<td>questionable since the authors only reported a "background" level in the room that was "lower than 40 dB(A)". Correct background measurements for audiometry require different maximum backgrounds for specific frequencies.
Selection of workers was not described. Classification of workers to exposure categories was not fully described. Potential confounders were not evaluated.
Authors identify as a limitation that there is "room for improvement between the normality and pseudo normalisation LV filling of the E/A ratio echocardiography parameter."</td>
</tr>
<tr>
<td colspan="5">**Results**
The abnormality rate of the echocardiography parameter E/A ratio within the LFN group was greater than both the GN and control group members. The abnormality of E/A ratio between the latter two groups did not show any difference.
Severe dysfunction cases (E/A ratio > 3) only occurred in LFN group members. The hearing loss caused by LFN exposure was more severe at higher frequencies, 4 kHz and 6 kHz and the loss of hearing could reach above 40 dB.
Authors reported: "…for the LFN group, the averaged value of the E/A ratio echocardiography parameter was found to be greater than 1.5 (which is the standard for grade of the JACC classification). The abnormality rate of the E/A ratio (E/A > 2) was found to be close to 31% in LFN group members, which was much higher than that of the GN and control groups. …[H]earing loss for the LFN and GN groups became serious at higher frequencies, especially at 4k [Hz] and 6k [Hz] where the hearing loss of the LFN group reached 40 dB, and was 10 dB higher than that of GN group. …[T]here was a 20 dB higher hearing loss in the LFN group when compared with the control group."
Conclusion
Authors concluded "Low frequency noise has a tremendous effect on human health both psychologically and physically."</td>
</tr>
</table>

<table>
<tr><th>Persson Waye 1997</th><th>Design</th><th>Exposure</th><th>Outcome</th><th>Limitations</th></tr>
<tr><td colspan="5"><i>Parallel Evidence</i></td></tr>
<tr>
<td>Aim
To assess evaluating effects of LFN on performance. Of special interest was to study objective and subjective effects on performance involving cognitive aspects over time.</td>
<td>Laboratory pilot study of 14 students with self-reported sensation of eardrum pressure after exposure to a LFN.</td>
<td>The study involved two exposure conditions: (1) predominantly mid frequency character (mid frequency noise) and (2) predominantly low frequency character (LFN).
Participants performed three computerised cognitive tests in the mid frequency or LFN condition alternatively. The first two cognitive tests were performed together with a secondary task (intended to create an interactive environment which led to a competition of cognitive resources).</td>
<td>Questionnaires were used to evaluate subjective symptoms, effects on mood and estimated interference with test results due to temperature, light and noise.
Mood was measured pre-test and post-test.
Post-test questionnaire was on subjective symptoms that had earlier been found to be associated with LFN (e.g. headache, pressure, fatigue) and symptoms were not previously found to be associated with LFN (e.g. eye irritation).</td>
<td>Only subjective effects were investigated.
Small sample drawn from university student population which is not representative of the general population.
Volunteers were pre-screened and included or excluded from the testing based on self-reported sensation of eardrum pressure following exposure to LFN, further limiting the representativeness of the study to the general population.
Analyses had very low power, and subsequently non-significant effects and trends were reported.</td>
</tr>
<tr><td colspan="5">Results
Subjects reported greater interference of task performance for LFN than mid frequency noise (p < 0.05). Exposure to LFN resulted in lower ‘social orientation’ (p < 0.05) (i.e. less agreeable, less co-operative) and tendency to lower ‘pleasantness’ (p = 0.07) (more bothered, less content), compared to the mid-frequency noise. Response times during the last part of the test were longer in the LFN exposure condition. The difference in annoyance between the LFN and the mid-frequency noise was not statistically significant (p = 0.19).
Conclusion
Authors concluded “that the LFN was estimated to interfere more strongly with performance. The results also gave some indication that cognitive demands were less well coped with under the LFN condition. This effect was especially pronounced in the last parts of the test, which indicates that the effects appear over time. The relation between the reduced activity and response time, which was especially pronounced in the low frequency noise condition, may also indicate that increased fatigue was of importance for the results.”</td></tr>
</table>

Persson Waye 2001	**Design**	**Exposure**	**Outcome**	**Limitations**
Parallel Evidence				
Aim: To study the possible interference of LFN on performance and annoyance.	Experimental study testing the impact of LFN exposure (ventilation noises) on cognitive performance and self-reported annoyance. 32 young adults (male = 13, female = 19, mean age = 23 years, SD = 2.6 years) with high or low sensitivity to noise in general or specifically to LFN took part in the study. Participants' sensitivity to noise in general and specifically LFN assessed by questionnaire. Participants underwent a hearing test, and only those with normal hearing (< 20 dB HL) included. Participants took part in two test sessions, on separate days.	This study involved exposure to two ventilation noise conditions: • predominantly low frequency content noise (in the frequency of 31.5 Hz to 125 Hz generated using a digital sound processor system, with the third octave band centred at 31.5 Hz and amplitude-modulated at a frequency of 2 Hz). • flat frequency content noise (control, recorded noise from a ventilation installation) Both conditions had a sound pressure level of 40 dBA.	Change in performance of various tasks designed to involve different levels of mental processing: Task I – simple reaction-time task Task II – short-term memory task Task III – proof-reading task Task IV – computerised verbal grammatical reasoning task Participants' self-reported reactions were also collected by questionnaire. Saliva samples taken to assess stress and cortisol levels were measured. Questionnaire measuring perceived stress and energy.	Small sample size (n = 32), particularly when sub-divided into groups by sensitivity to general and LFN. "Noise sensitivity" was not clearly defined and evaluated by questionnaire with no other information provided. Participants were young with normal hearing, were recruited by public advertising and were paid. Possible recruitment bias but detailed demographics of subjects were not provided. Participants' literacy and numeracy was not reported.
Results Exposure to LFN condition resulted in poorer performance on some aspects of cognitive tasks and LFN appeared to impair working capacity more than reference noise. LFN was associated with reduced number of errors identified per line read in a proof-reading task and reduced improvement over time during the verbal grammatical reasoning task. Subjects rated LFN more annoying than reference noise and also considered LFN impaired working capacity more than reference noise. No associations were found between noise and other symptoms. Subjects reported a higher degree of annoyance and impaired working capacity when working exposed to LFN. Impaired working capacity and annoyance due to LFN were significantly correlated to subjective outcomes, such as a feeling of pressure on the head, tiredness, and lack of concentration. Three-way interaction in response time between noise, phase and LFN sensitivity ($p < 0.05$). - subjects with high-sensitivity to LFN decreased their response time considerably during reference noise, but only slightly during LFN (reverse observed for subjects low-sensitive to LFN). - subjects with high-sensitivity to noise in general decreased their response time during LFN, but only slightly during reference noise (subjects low-sensitive only decreased their response time during reference noise). Effects were more pronounced among subjects classified as sensitive to low-frequency noise and to noise in general. Noise-sensitive subjects reported more annoyance and impaired working capacity, particularly low-frequency sensitive individuals.				

- tendency to a two-way interaction in reaction-time between noise and sensitivity to noise in general (p = 0.051); subjects with high-sensitivity to noise in general had a somewhat longer reaction-time during the LFN condition compared to the reference noise condition, whereas low-sensitivity subjects had similar reaction times during both noise conditions. **Conclusion** Authors concluded "…the quality of work performance and perceived annoyance may be influenced by the continuous exposure to LFN at commonly occurring noise levels."

Smith 2013	**Design**	**Exposure**	**Outcome**	**Limitations**
Parallel Evidence				
Aim To ascertain the increasing vibration amplitude, associated with passing railway trains, on sleep disturbance.	Laboratory study of 12 participants to investigate the impact of increasing vibration amplitudes (horizontal vibrations) simulating passing freight trains on individuals sleep disturbance (sleep parameters) and heart rates (cardiovascular response).	Participants slept for six consecutive nights in a laboratory. Beginning with one night of habituation, followed by one night of controlled sleep followed by four nights of randomised order exposure. Exposure nights considered of 36 pass by train simulations, varying vibration level (noise only, low (W_d Weighted maximum acceleration 0.0058 m/sec^2), moderate (0.0102 m/sec^2), high (0.0204 m/sec^2)) between nights.	Questionnaires measured subjective sleep indicators (including tiredness and stress) completed at both morning and evening. Sleeping parameters were obtained through use of polysomnography (PSG). Heart rate activity was recorded during the night period through use of a single ECG. Breathing measurements were also obtained. An EEG was used to establish artefacts and wake stages to be excluded from the heart rate analysis, due to prior unforeseen technical limitations due to unsuitability for task.	Laboratory environment may not accurately replicate real-world exposures. Small study group (n = 12) and young age (20-29 years) limits generalisability. Unable to draw a conclusion regarding the impacts of the individual train's characteristics, including rise time and event duration.
Results Quality of sleep was seen to decrease significantly with the increased level of vibration (p = 0.033, F(3,7) = 6.1), participants felt increasingly disturbed by the vibrations with increasing amplitudes (p = 0.002, F(3,8) = 16.2). Levels of stress were increased the evening after a night of increased vibration (previous night) (p = 0.048). Specific sleep parameters showed clear influence of the applied vibration and this effect was significant in subscales of poor sleep, difficultly falling asleep and tiredness in the				

morning (each $p < 0.05$). In contrast participants' rating of being disturbed by noise did not change significantly with increasing vibration amplitude ($p = 0.626$). An overall heart rate increase was observed during an increased amplitude of vibration ($p = 0.054$, $F(3,4) = 7.3$). With increasing vibration, a decrease in latency was found and an increase in amplitude of heart rate, as well as a reduction in sleep quality and sleep disturbance, was observed. **Conclusion** Authors concluded that "individuals are able to differentiate between train induced vibration and train induced noise during the night and that train induced vibration and LFN has a negative effect on their self-reported sleep quality, causes subjective sleep disturbance and is accompanied by heart rate increase. The effects increase with greater vibration amplitude. The results suggest that individuals living near to railway lines and thus subjected to the accompanying noise and vibration exposure are at risk for having their sleep impaired. This may lead to reduced concentration and daytime functioning in the short term and impaired health in long term."

Witthoft 2013	**Design**	**Exposure**	**Outcome**	**Limitations**
Parallel Evidence				
Aim To test whether exposure to a media report promoting a link between Wi-Fi and symptoms would influence symptom attribution during sham Wi-Fi exposure.	'Between-groups' experiment. 147 university students randomly assigned to experimental (watch a television report about the adverse health effects of Wi-Fi, n = 76) or control groups (report of the same length but relating to the security of mobile phone data transmission, n = 71). Positively skewed symptom reports and questionnaire data were log-transformed where necessary; effects of television report on concerns about EMF tested using linear regression analysis; t-tests to test the difference in symptom scores before and after sham exposure.	Exposure to either a television report (genuine report aired on UK television) about the adverse health effects of Wi-Fi or a control film. Subsequently exposed to a 'sham' Wi-Fi signal (15 minutes). Exposure equipment (antenna mounted on a headband, seemingly connected to a Wi-Fi router and laptop) was attached to the participant's head.	Symptoms were assessed with a modified state version of the checklist for symptoms in daily life (CSD) following the sham exposure. Secondary outcomes measures included worries regarding the health effects of EMF, attributing symptoms to the sham exposure and increases such as perceived sensitivity to EMF. Perceived EMF sensitivity was evaluated using EMF version of the Sensitive Soma Assessment Scale (SSAS). Worries about the health effects of EMF measured using Modern Health Worries Scale (MHW-R). State of anxiety was assessed using State Trait Anxiety Inventory (STAI-6), somatisation was	Did not use a 'no exposure' control condition and therefore cannot definitively rule out the nocebo effect, however authors argue that nocebo is unlikely given the magnitude of the effects found and the consistency with *a priori* expectations. Symptoms reports were influenced by the demand characteristics of the study rather than the actual symptom experience. There was a lack of baseline measurement resulting in a lack of ability to relate inference between film and symptom report. Sample drawn from university student population which is not representative of the general population.

<table>
<tr><td></td><td></td><td></td><td>assessed using Patient Health Questionnaire (PHQ-15) and somatosensory amplification was assessed using Somatosensory Amplification Scale (SSA).</td><td>Participants were paid for their involvement in the study.
Study did not systematically assess the current and previous medical and psychiatric conditions of participants, therefore cannot rule out the possibility that these factors might have influenced results.</td></tr>
<tr><td colspan="5">Results
82 of the 147 participants (56%) reported symptoms which were attributed to the sham exposure. The film shown to the experimental group found: EMF related worries (B = 0.19; P = 0.019)* were strongest in people with high levels of anxiety state; post sham exposure symptoms were found among participants with high pre-existing anxiety (B = 0.22; P = 0.008)*; the likelihood of symptoms being attributed to the sham exposure among people with high anxiety (B = 0.31; P = 0.001)*; and the likelihood of people who attributed their symptoms to the sham exposure believing themselves to be sensitive to EMF (B = 0.16; P = 0.049)*
*B = Beta
Conclusion
Authors concluded that “Media reports about the adverse effects of supposedly hazardous substances can increase the likelihood of experiencing symptoms following sham exposure and developing apparent sensitivity to it.”</td></tr>
</table>

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Appendix I – Systematic Review Questions

SRQ1. Distance

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, (ii) bias, or (iii) confounding?

SRQ2. Audible noise

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?

SRQ3. Infrasound and low-frequency noise

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?

SRQ4. Shadow flicker

Is there any reliable evidence of an association between shadow flicker (photosensitivity 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?

SRQ5. Electromagnetic radiation

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?

Appendix 2 – Database search strategies

Searches were first run on 19 March 2014 (#2) and repeated on 7 May 2014 (#4)

Databases	**Set**	**Query**	**Hits**
PubMed	#1	((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])	4225
	#2	#1 AND ("2012/10/01"[Date - Entrez] : "3000"[Date - Entrez])	460
	#3	((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])	4292
	#4	#3 AND ("2014/03/19"[Date - Entrez] : "3000"[Date - Entrez])	35
EMBASE **via** **embase.com**	#1	wind OR ‘wind’/exp AND (turbine* OR tower* OR farm OR farms OR ‘energy generating resources’/exp OR ‘energy generating resources’ OR ‘electric power supplies’/exp OR ‘electric power supplies OR power OR ‘technology’/exp OR technology OR ‘power supply’/exp OR ‘power supply’ OR ‘energy resource’/exp OR ‘energy resource’) OR ‘wind turbine syndrome’ OR ‘wind power’/exp	4471
	#2	#1 AND [26-9-2012]/sd	619
	#3	wind OR 'wind'/exp AND (turbine* OR tower* OR farm OR farms OR 'energy generating resources'/exp OR 'energy generating resources' OR 'electric power supplies'/exp OR 'electric power supplies' OR power OR 'technology'/exp OR technology OR 'power supply'/exp OR 'power supply' OR 'energy resource'/exp OR 'energy resource') OR 'wind turbine syndrome' OR 'wind power'/exp	3962
	#4	#3 AND [19-3-2014]/sd	61
Cochrane Library	#1	"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"	1
	#2	Limit 2012-3000	0
	#3	"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"	1
	#4	Limit 2012-3000	0
PsycINFO via OVID	#1	(Wind and (turbine or tower or farm or power or "renewable energy" or "power plant" or technology or energy or resource)).mp.	196
	#2	limit 1 to yr="2012 -Current"	40
	#3	(Wind and (turbine or tower or farm or power or "renewable energy" or "power plant" or technology or energy or resource)).mp.	198
	#4	limit 3 to yr="2014 -Current"	8

Web of Science	#1	TS=((wind NEAR (turbine* OR tower* OR farm* OR power* OR "renewable energy" OR "power plant*" OR technolog* OR energy OR resourc*)) OR "wind turbine syndrome") AND TS=(health OR welfare OR well-being OR human OR noise OR glint OR flicker OR “electromagnetic radiation”) Timespan = 2012-2014	778
	#2	Refined by: WEB OF SCIENCE CATEGORIES: (ENERGY FUELS OR ENGINEERING INDUSTRIAL OR IMMUNOLOGY OR ENGINEERING ELECTRICAL ELECTRONIC OR ENGINEERING MECHANICAL OR MATERIALS SCIENCE MULTIDISCIPLINARY OR ENGINEERING CIVIL OR ACOUSTICS OR BIOTECHNOLOGY APPLIED MICROBIOLOGY OR MICROBIOLOGY OR ENVIRONMENTAL SCIENCES OR OPHTHALMOLOGY OR OPTICS OR OTORHINOLARYNGOLOGY OR MECHANICS OR PATHOLOGY OR ENVIRONMENTAL STUDIES OR PHARMACOLOGY PHARMACY OR MATERIALS SCIENCE CHARACTERIZATION TESTING OR PLANNING DEVELOPMENT OR PRIMARY HEALTH CARE OR PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH SCI OR ECOLOGY OR ENGINEERING ENVIRONMENTAL OR ENGINEERING MULTIDISCIPLINARY OR MULTIDISCIPLINARY SCIENCES OR PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH OR ORNITHOLOGY OR DERMATOLOGY OR MEDICINE RESEARCH EXPERIMENTAL OR BIOCHEMICAL RESEARCH METHODS OR ONCOLOGY OR CONSTRUCTION BUILDING TECHNOLOGY OR DEVELOPMENTAL BIOLOGY OR MEDICINE GENERAL INTERNAL OR CARDIAC CARDIOVASCULAR SYSTEMS OR BIOLOGY OR PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH SSCI OR ENGINEERING BIOMEDICAL OR ENGINEERING CHEMICAL)	619
	#3	TS=((wind NEAR (turbine* OR tower* OR farm* OR power* OR "renewable energy" OR "power plant*" OR technolog* OR energy OR resourc*)) OR "wind turbine syndrome") AND TS=(health OR welfare OR well-being OR human OR noise OR glint OR flicker OR “electromagnetic radiation”) Timespan = 2014	82
	#4	Refined by: WEB OF SCIENCE CATEGORIES: (ENERGY FUELS OR ENGINEERING MECHANICAL OR ENGINEERING CIVIL OR ACOUSTICS OR ECOLOGY OR ENGINEERING ELECTRICAL ELECTRONIC OR ENVIRONMENTAL SCIENCES OR BIOTECHNOLOGY APPLIED MICROBIOLOGY OR MEDICAL INFORMATICS OR MEDICINE RESEARCH EXPERIMENTAL OR MULTIDISCIPLINARY SCIENCES OR ENVIRONMENTAL STUDIES OR ONCOLOGY OR PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH OR ENGINEERING MULTIDISCIPLINARY)	70

Appendix 3 – Background Review 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?

Appendix 4 – Citations from the repeat literature search

Reasons for exclusion

1 = not publicly available in English

2 = not based on systematically collected data relevant to wind farms and human health

3 = does not look at human exposure to wind farm emissions

4 = exclusively selects participants only because they had reported health effects

5 = does not compare participants with different levels of exposure to wind turbines

6 = does not explain how the data were collected

7 = does not report on one or more health (or health-related) outcomes

8 = does not analyse the results

9 = citation was considered (and either included or excluded) for the Independent Review

CITATION	REASON
Adcock J, Delaire C, Griffin D. A Review of the Draft NSW Planning Guidelines: Wind Farms. *Acoustics Australia*. 2012;40(1):72-8.	9
Alimohammadi I, Sandrock S, Gohari MR. The effects of low frequency noise on mental performance and annoyance. *Environmental Monitoring and Assessment*. 2013;185(8): 7043-51.	2, 3
Alway P. Wind Farm Noise. *Acoustics Australia*. 2013;41(3):195.	2 [letter]
Ammar M, IEEE. Flicker Emission of Distributed Wind Power: A Review of Impacts, Modeling, Grid Codes and Mitigation Techniques. New York: IEEE; 2012.	7
Ammar M, Joos G. Impact of Distributed Wind Generators Reactive Power Behavior on Flicker Severity. *IEEE Transactions on Energy Conversion*. 2013;28(2):425-33.	7
Angulo I, de la Vega D, Grande O, Cau N, Gil U, Wu YY, et al. Empirical Evaluation of the Impact of Wind Turbines on DVB-T Reception Quality. *IEEE Transactions on Broadcasting*. 2012;58(1):1-9.	7
Baath LB. Noise spectra from wind turbines. *Renewable Energy*. 2013;57:512-9.	5, 7
Bakker RH, Pedersen E, van den Berg GP, Stewart RE, Lok W, Bouma J. Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress. *Science of the Total Environment*. 2012;425:42-51.	9
Barnard M. Issues of wind turbine noise. *Noise & Health*. 2013;15(63):150-2.	2, 5 [letter]
Baxter J, Morzaria R, Hirsch R. A case-control study of support/opposition to wind turbines: Perceptions of health risk, economic benefits, and community conflict. *Energy Policy*. 2013;61:931-43.	2, 3, 7
Bidwell DC. The structure and strength of public attitudes towards wind farm development. *Dissertation Abstracts International Section A: Humanities and Social Sciences*. 2012;72(7-A):2598.	7
Bilski B. 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*. 2012;21(2):289-95.	9
Bockstael A, Dekoninck L, Can A, Oldoni D, De Coensel B, Botteldooren D. Reduction of Wind Turbine Noise Annoyance: An Operational Approach. *Acta Acustica united with Acustica*. 2012;98(3):392-401.	Background Evidence
Bolin K, Almgren M, Ohlsson E, Karasalo I. Long term estimations of low frequency noise levels over water from an off-shore wind farm. *Journal of the Acoustical Society of America*. 2014;135(3):1106.	7

CITATION	REASON
Adcock J, Delaire C, Griffin D. A Review of the Draft NSW Planning Guidelines: Wind Farms. *Acoustics Australia*. 2012;40(1):72-8.	9
Bolin K, Kedhammar A, Nilsson ME. The Influence of Background Sounds on Loudness and Annoyance of Wind Turbine Noise. *Acta Acustica united with Acustica*. 2012;98(5):741-8.	7
Bowdler D. Wind turbine syndrome – an alternative view. *Acoustics Australia*. 2012;40(1):67-71.	9
Broner N. Special issue wind turbine noise. *Acoustics Australia*. 2012;40(1):5-83.	7
Camp S. The steep and the tearful: a New Zealand perspective of wind turbine noise. *Acoustics Australia*. 2012;40(1):57-8.	7
Chapman S, St George A, Waller K, Cakic V. The pattern of complaints about Australian wind farms does not match the establishment and distribution of turbines: support for the psychogenic, 'communicated disease' hypothesis. *PLoS One*. 2013;8(10):e76584.	5
Chapman S, St George A. How the factoid of wind turbines causing 'vibroacoustic disease' came to be 'irrefutably demonstrated'. *Australian and New Zealand Journal of Public Health*. 2013;37(3):244-9.	5 [review]
Chapman S. Wind Turbine Noise Editorial ignored 17 reviews on wind turbines and health. *BMJ*. 2012;344:1.	9
Chourpouliadis C, Ioannou E, Koras A, Kalfas AI. Comparative study of the power production and noise emissions impact from two wind farms. *Energy Conversion and Management*. 2012;60:233-42.	7
Crichton F, Dodd G, Schmid G, Gamble G, Cundy T, Petrie KJ. The power of positive and negative expectations to influence reported symptoms and mood during exposure to wind farm sound. *Health Psychology*. 2013. [Epub ahead of print 25/11/2013]	Mechanistic Evidence
Crichton F, Dodd G, Schmid G, Gamble G, Petrie KJ. Can expectations produce symptoms from infrasound associated with wind turbines? *Health Psychology*. 2014;33(4):360-4.	Mechanistic Evidence
Deignan B, Harvey E, Hoffman-Goetz L. Fright factors about wind turbines and health in Ontario newspapers before and after the Green Energy Act. *Health, Risk and Society*. 2013;15(3):234-50.	3, 5, 7
Doolan CJ, Moreau DJ. An on-demand simultaneous annoyance and indoor noise Recording Technique. *Acoustics Australia*. 2013;41(2):141-5.	Background Evidence
Ejdys J, Broniewicz E. Impact of wind power plants on acoustic climate. *Przeglad Elektrotechniczny*. 2012;88(3A):199-202.	7
Enbom H, Enbom IM. Infrasound from wind turbines: an overlooked health hazard. *Lakartidningen*. 2013;110(32-33):1388-9.	2
Evans T, Cooper J. Comparison of predicted and measures wind farm noise levels and implications for assessments of new wind farms. *Acoustics Australia*. 2012;40(1):28-36.	7
Farboud A, Crunkhorn R, Trinidade A. 'Wind turbine syndrome': fact or fiction? *Journal of Laryngology and Otology*. 2013;127(3):222-6.	2 [review]
Groth TM, Vogt C. Residents' perceptions of wind turbines: An analysis of two townships in Michigan. *Energy Policy*. 2014;65:251-60.	7
Haggett C. The Social Experience of Noise from Wind Farms. *Learning from Wind Power: Governance, Societal and Policy Perspectives on Sustainable Energy*. 2012:153-73.	2, 7 [book chapter]
Hanning CD, Evans A. Wind turbine noise. Authors' reply to Chapman. *BMJ*. 2012;344:1.	9
Hanning CD, Evans A. Wind turbine noise. *BMJ*. 2012;344:2.	9
Hume KI, Brink M, Basner M. Effects of environmental noise on sleep. *Noise & Health*. 2012;14(61):297-302.	2 [review]
Jeffery RD, Krogh C, Horner B. Adverse health effects of industrial wind turbines. *Canadian Family Physician/Médecin de Famille Canadien*. 2013;59(5):473-5.	2, 3, 5

CITATION	REASON
Adcock J, Delaire C, Griffin D. A Review of the Draft NSW Planning Guidelines: Wind Farms. *Acoustics Australia*. 2012;40(1):72-8.	9
Jeffery RD, Krogh CM, Horner B. Industrial wind turbines and adverse health effects. *Canadian Journal of Rural Medicine/Journal Canadien de la Médecine Rurale*. 2014;19(1):21-6.	6 [review]
Jianu O, Rosen MA, Naterer G. Noise Pollution Prevention in Wind Turbines: Status and Recent Advances. *Sustainability*. 2012;4(6):1104-17.	7
Katsaprakakis DA. A review of the environmental and human impacts from wind parks. A case study for the Prefecture of Lasithi, Crete. *Renewable and Sustainable Energy Reviews*. 2012;16(5):2850-63.	7
Kontogianni A, Tourkolias C, et al. Planning globally, protesting locally: Patterns in community perceptions towards the installation of wind farms. *Renewable Energy*. 2014;66:170-7.	7
Koulouras G, Alves-Pereira M, et al. Letter to the Editor re: 'How the factoid of wind turbines causing 'vibroacoustic disease' came to be 'irrefutably demonstrated'. *Scientific World Journal*. 2014;38(2):191-2.	2, 4, 5
Kurpas D, Mroczek B, Karakiewicz B, Kassolik K, Andrzejewski W. Health impact of wind farms. *Annals of agricultural and environmental medicine: AAEM*. 2013;20(3):595-604.	2, 5, 6 [review]
Larsson C, Ohlund O. Amplitude modulation of sound from wind turbines under various meteorological conditions. *Journal of the Acoustical Society of America*. 2014;135:67-73.	7
Lee GS, Cheong C, Shin SH, Jung SS. A case study of localization and identification of noise sources from a pitch and a stall regulated wind turbine. *Applied Acoustics*. 2012;73(8):817-27.	7
Lee S, Lee S, Lee S. Numerical modeling of wind turbine aerodynamic noise in the time domain. *Journal of the Acoustical Society of America*. 2013;133(2):El94-100.	5, 7
Leung DYC, Yang Y. Wind energy development and its environmental impact: A review. *Renewable and Sustainable Energy Reviews.* 2012;16(1):1031-9.	7
Maffei L, Iachini T, Masullo M, Aletta F, Sorrentino F, Senese VP, et al. The effects of vision-related aspects on noise perception of wind turbines in quiet areas. *International Journal of Environmental Research and Public Health*. 2013;10(5):1681-97.	7
Maille ME, Saint-Charles J. Social cohesion in a community divided by a wind farm project. *Human Ecology Review*. 2012;19(2):83-98.	5
McCallum LC, Whitfield Aslund ML, Knopper LD, Ferguson GM, Ollson CA. Measuring electromagnetic fields (EMF) around wind turbines in Canada: is there a human health concern? *Environmental Health*. 2014;13(1):9.	Background Evidence
McDonald NC, Pearce JM. Community Voices: Perspectives on Renewable Energy in Nunavut. *Arctic*. 2013;66(1):94-104.	2, 3, 5, 7
Moynihan MJ. Wind energy presents new challenges for worker health and safety. *Workplace Health & Safety*. 2013;61(5):232.	2, 3, 5, 7
Mroczek B, Kurpas D, Karakiewicz B. Influence of distances between places of residence and wind farms on the quality of life in nearby areas. *Annals of Agricultural and Environmental Medicine: AAEM*. 2012;19(4):692-6.	Direct Evidence
Mulvaney KK, Woodson P, Prokopy LS. Different shades of green: a case study of support for wind farms in the rural Midwest. *Environmental Management.* 2013;51(5):1012-24.	3, 5, 7
Nilsson ME, Bolin K, Bluhm G. [Wind power noise is not an infrasound problem]. *Lakartidningen*. 2013;110(42):1877.	1
Nissenbaum MA, Aramini JJ, Hanning CD. Effects of industrial wind turbine noise on sleep and health. *Noise & Health*. 2012;14(60):237-43.	9

CITATION	REASON
Adcock J, Delaire C, Griffin D. A Review of the Draft NSW Planning Guidelines: Wind Farms. *Acoustics Australia*. 2012;40(1):72-8.	9
Ollson CA, Knopper LD, McCallum LC, Whitfield-Aslund ML. Are the findings of "Effects of industrial wind turbine noise on sleep and health" supported? *Noise & Health*. 2013;15(63):148-50.	2, 5, 7 [letter]
Parks JM, Theobald KS. Public engagement with information on renewable energy developments: The case of single, semi-urban wind turbines. *Public Understanding of Science*. 2013;22(1):49-64.	2, 5, 7
Pohl J, Hubner G, Mohs A. Acceptance and stress effects of aircraft obstruction markings of wind turbines. *Energy Policy*. 2012;50:592-600.	Direct Evidence
Read DL, Brown RF, Thorsteinsson EB, Morgan M, Price I. The theory of planned behaviour as a model for predicting public opposition to wind farm developments. *Journal of Environmental Psychology*. 2013;36:70-6.	7
Roberts JD, Roberts MA. Wind turbines: is there a human health risk? *Journal of Environmental Health*. 2013;75(8):8-13, 6-7.	2
Ruotolo F, Senese VP, Ruggiero G, Maffei L, Masullo M, Iachini T. Individual reactions to a multisensory immersive virtual environment: The impact of a wind farm on individuals. *Cognitive Processing*. 2012;13(Suppl 1):S319-S23.	Mechanistic Evidence
Schiff MT, Magari SR, Smith CE, Rohr AC. Field evaluation of wind turbine-related noise in western New York State. *Noise Control Engineering Journal*. 2013;61(5):509-19.	Background Evidence
Seltenrich N. Wind turbines: a different breed of noise? *Environmental Health Perspectives*. 2014;122(1):A20-5.	2, 5
Shepherd D. Wind farms and health: who is fomenting community anxieties? *Medical Journal of Australia*. 2012;196(2):108.	9
Siler-Evans K, Azevedo IL, Morgan MG, Apt J. Regional variations in the health, environmental, and climate benefits of wind and solar generation. *Proceedings of the National Academy of Sciences of the United States of America*. 2013;110(29):11768-73.	7
Takahashi Y. Present situation and research task on the assessment of psychological effects caused by low-frequency noise. *Nihon Eiseigaku Zasshi*. 2013;68(2):88-91.	1
Taylor J, Eastwick C, Lawrence C, Wilson R. Noise levels and noise perception from small and micro wind turbines. *Renewable Energy*. 2013;55:120-7.	Mechanistic Evidence
Taylor J, Eastwick C, Wilson R, Lawrence C. The influence of negative oriented personality traits on the effects of wind turbine noise. *Personality and Individual Differences*. 2013;54(3):338-43.	Direct Evidence
Tickell C. Low Frequency, Infrasound and amplitude modulation noise from wind farms: some recent findings. *Acoustics Australia*. 2012;40(1):64-6.	Background Evidence
van Renterghem T, Bockstael A, De Weirt V, Botteldooren D. Annoyance, detection and recognition of wind turbine noise. *Science of the Total Environment*. 2013;456-457:333-45.	Background Evidence
Whitfield Aslund ML, Ollson CA, Knopper LD. Projected contributions of future wind farm development to community noise and annoyance levels in Ontario, Canada. *Energy Policy*. 2013;62:44-50.	2

Appendix 5 – Submitted literature

CITATIONS OF SUBMITTED LITERATURE	CATEGORY	REASON
Access Economics. Listen hear! The economic impact and cost of hearing loss in Australia. Access Economics Pty Ltd, 2006.	Exclude	Not related to exposures or outcomes related to wind farms
Acoustic Group. Peer review of environmental noise assessment Collector Wind Farm 42.5006.R1:ZSC. The Acoustic Group, 2013.	Exclude	Not based on new (or new analysis of) systematically collected data
Alves-Pereira M, Branco NA. Letter to the Editor - How the factoid of wind turbines causing 'vibroacoustic disease' came to be 'irrefutably demonstrated'. *Aust NZ J Public Health*. 2013;38(2):191-92.	Exclude	Letter; refers to previously published findings
Alves-Pereira M, Castelo Branco NA. Vibroacoustic disease: biological effects of infrasound and low-frequency noise explained by mechanotransduction cellular signalling. *Progress in biophysics and molecular biology*. 2007;93(1-3):256-79.	Exclude	Already considered and either included or excluded from the Independent Review
AMA. AMA Position Statement Wind Farms and Health: Australian Medical Association; 2014.	Exclude	Position statement; not based on new (or new analysis of) systematically collected data
Ambrose SE, Rand RW, Krogh CME. Falmouth, Massachusetts wind turbine infrasound and low frequency noise measurements Inter-noise 2012; 19-22 August; New York City, NY 2012.	Exclude	Summary of previously published paper
Ambrose SE, Rand RW, Krogh CME. Wind Turbine Acoustic Investigation: Infrasound and Low-Frequency Noise A Case Study. *Bull Sci Technol Soc*. 2012.	Exclude	Case study only; not based on new (or new analysis of) systematically collected data
Ambrose SE, Rand RW. The Bruce McPherson Infrasound and Low Frequency Noise Study Adverse Health Effects Produced By Large Industrial Wind Turbines Confirmed. 2011.	Exclude	Measurements at one turbine; not based on new (or new analysis of) systematically collected data
Andreucci F, Atzori D, Baratta C, Betti R. Correlation between people perception of noise from large wind turbines and measured noise levels. 5th International Conference on Wind Turbine Noise 28-30 August 2013; Denver.	Exclude	Conference abstract only
Arra I, Lynn H. Literature review 2013: Association between wind turbine noise and human distress. 2013.	Exclude	Review of previously published articles and presents no original findings not already considered in the Independent Review and this update. Provides no additional evidence on the likely level of exposure to emissions, Mechanistic data or any Parallel data

CITATIONS OF SUBMITTED LITERATURE	CATEGORY	REASON
Association of Australian Acoustical Consultants. Wind farm position statement. Undated.	Exclude	Position statement; not based on new (or new analysis of) systematically collected data
Aughey, A, Transcript of evidence: Hearing before the Select Committee on Wind Farm Developments in South Australia (2013).	Exclude	Legal proceedings; not based on new (or new analysis of) systematically collected data
Australian Wind Energy Assoc. Wind farming, electromagnetic radiation and interference, Fact Sheet No. 10. Canberra: Australian Greenhouse Office; undated.	Exclude	Fact sheet; not based on new (or new analysis of) systematically collected data
Australian Wind Energy Assoc. Wind farms and noise, Fact Sheet No. 6. Canberra: Australian Greenhouse Office; undated.	Exclude	Fact sheet; not based on new (or new analysis of) systematically collected data
Babisch W. Updated exposure-response relationship between road traffic noise and coronary heart diseases: a meta-analysis. *Noise Health*. 2014;16(68):1-9.	Exclude	Does not provide additional evidence of likely level of emissions produced by wind farms, no Mechanistic evidence and no Parallel Evidence
Bakker H, Bennett D, Rapley B, Thorne R. Seismic effect on residents from 3 MW wind turbines. 3rd International Meeting on Wind Turbine Noise; 17-19 Jun; Aalborg Denmark 2009.	Exclude	Conference abstract
Barnard M. [RS] Issues of wind turbine noise. *Noise Health*. 2013;15(63):150-2.	Exclude	Letter; not based on new (or new analysis of) systematically collected data
Bell A. Annoyance from wind turbines: role of the middle ear muscles. *Acoustics Aust*. 2014;40:60.	Exclude	Letter, not based on new (or new analysis of) systematically collected data
Bell A. How do middle ear muscles protect the cochlea? Reconsideration of the intralabyrinthine pressure theory. *J Hearing Sci*. 2011;1(2):9-23.	Exclude	Not related to wind farms
Berglund B, Lindvall T, Schwela D. Guidelines for community noise. WHO, 1999.	Exclude	Guidelines; not based on new (or new analysis of) systematically collected data
Berglund B, Lindvall T. Community noise. *Arch Center Sens Res*. 1995;2(1):1-195.	Exclude	Not based on new (or new analysis of) systematically collected data
Bernert RA, Joiner TE. Sleep disturbances and suicide risk: A review of the literature. *Neuropsychiatr Dis Treat*. 2007;3(6):735-43.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected data; no analysis of results and no exposures of any relevance to wind turbines
Bilski B. Factors influencing social perception of investments in the wind power industry with analysis of the most significant environmental factor - noise. *Pol J Environ Stud*. 2012;21(2):289-95.	Exclude	Already considered and either included or excluded from the Independent Review
Black O. Submission to Planning Hearing, Illinois USA. 2009.	Exclude	Legal proceedings; not based on new (or new analysis of) systematically collected data

CITATIONS OF SUBMITTED LITERATURE	CATEGORY	REASON
Branco NA, Alves-Pereira M. Vibroacoustic disease. *Noise Health*. 2004;6(23):3-20.	Exclude	Narrative paper; not based on new (or new analysis of) systematically collected data
Branco NA. Low frequency noise: A major risk factor in military operations. RTO AVT Symposium on Ageing Mechanisms and Control; 8-11 October 2001; Manchester, 2001.	Exclude	Narrative review not based on new (or new analysis of) systematically collected data; no analysis of results
Bray W. Relevance and applicability of the Soundscape concept to physiological or behavioural effects caused by a noise at very low frequencies which may not be audible. Acoustical Society of America 164th Meeting; 26 October 2012; Kansas City 2012.	Exclude	Conference abstract
Brinckerhoff P. Update of UK Shadow Flicker Evidence Base. Department of Energy and Climate Change.	Background Evidence	Government report; shadow flicker exposure data
Bronzaft AL. The noise from wind turbines: Potential adverse impacts on children's well-being. *Bull Sci Technol Soc*. 2011;31:256.	Exclude	Already considered and either included or excluded from the Independent Review
Buck S, Palo S, Moriarty P. Application of phased array techniques for amplitude modulation mitigation. 5th International Conference on Wind Turbine Noise 28-30 August 2013; Denver.	Exclude	Conference abstract
Canada Health. Canadian handbook on health impact assessment: Vol. 1. The basics. 2004.	Exclude	Guidelines; not based on new (or new analysis of) systematically collected data
Cappuccio FP, Cooper D, D'Elia L, Strazzullo P, Miller MA. Sleep duration predicts cardiovascular outcomes: a systematic review and meta-analysis of prospective studies. *Eur Heart J.* 2011;32(12):1484-92.	Exclude	No evidence on likely level of exposure to emissions produced by wind farms; no Mechanistic or Parallel Evidence as covers no environmental exposures relevant to wind farms
Chao PC, Yeh CY, Juang YJ, Hu CY, Chen CJ. Effect of low frequency noise on the echocardiographic parameter E/A ratio. *Noise Health*. 2012;14(59):155-8.	Parallel Evidence	Occupational study of low frequency noise compared with a general noise group and a control group
Chapman S, St George A, Waller K, Cakic V. [RS] The pattern of complaints about Australian wind farms does not match the establishment and distribution of turbines: support for the psychogenic, 'communicated disease' hypothesis. *PloS one*. 2013;8(10):e76584.	Mechanistic Evidence	Collation of complaints from residents around wind farms obtained from a variety of sources
Chapman S, St George A. [RS] How the factoid of wind turbines causing 'vibroacoustic disease' came to be 'irrefutably demonstrated'. *Aust NZ J Public Health*. 2013;37(3):244-9.	Exclude	No evidence on likely level of exposure to emissions produced by wind farms; no Mechanistic or Parallel Evidence
Chapman S. Can wind farms make people sick? 2010; Available from: http://blogs.crikey.com.au/croakey/2010/02/23/can-wind-farms-make-people-sick-simon-chapman-investigates/.	Exclude	Not based on new (or new analysis of) systematically collected data

CITATIONS OF SUBMITTED LITERATURE	**CATEGORY**	**REASON**
Chapman S. Factoid forensics: Have "more than 40" Australian families abandoned their homes because of wind farm noise? In press.	Exclude	Not based on new (or new analysis of) systematically collected data
Chapman S. Psycho-social mediators of reported annoyance and putative health-related symptoms associated with wind turbines: a discussion starter. Presentation to NHMRC Scientific Forum. 2011.	Exclude	Not based on new (or new analysis of) systematically collected data
Chapman S. Response to S. Laurie critique of PLOS ONE article. [NB correct title to be inserted]. 2013.	Exclude	Letter; not based on new (or new analysis of) systematically collected data
Cherry Tree Farm Pty Ltd v Mitchell SC (Includes Summary) (Red Dot) [2013] VCAT 1939. Victorian Civil and Administrative Tribunal; 2013.	Exclude	Legal proceedings; not based on new (or new analysis of) systematically collected data
Chief Medical Officer of Health. Report: The potential health impact of wind turbines. Ontario, Canada: Ontario Agency for Health Protection and Promotion, Ontario Ministry of Health and Long-Term Care, Council of Ontario Medical Officers of Health, 2010.	Exclude	Guidelines; not based on new (or new analysis of) systematically collected data
Cidras J, Feijoo A, Carillo Gonzalez C. Synchronization of asynchronous wind turbines. *IEEE Transact Power Syst*. 2002;17:1162-69.	Exclude	Not based on new (or new analysis of) systematically collected data
Colby WD, Dobie R, Leventhall G, Lipscomb DM, McCunney RJ, Seilo MT, et al. Wind turbine sound and health effects: An expert panel review. Washington DC: American Wind Energy Association and Canadian Wind Energy Association, 2009.	Exclude	Already considered and either included or excluded from the Independent Review
Colby WD. Presentation to Nova Scotia Department of Energy. 2010.	Exclude	Not based on new (or new analysis of) systematically collected data
Cole PN, Krogh CME. Wind turbine facilities' perception: A case study from Canada. 5th International Conference on Wind Turbine Noise 28 - 30 August 2013; Denver.	Exclude	Conference abstract
Cooper SE. Peer review comments: South Australian EPA and Resonate Acoustics "Infrasound levels near windfarms and in other environments. The Acoustic Group, 2013.	Exclude	Opinion; not based on new (or new analysis of) systematically collected data
Cooper SE. Technical note: wind farm noise - An ethical dilemma for the Australian Acoustical Society? *Acoustics Aust*. 2012;40(2):139.	Exclude	Not based on new (or new analysis of) systematically collected data
Crichton F, Dodd G, Schmid G, Gamble G, Cundy T, Petrie KJ. The power of positive and negative expectations to influence reported symptoms and mood during exposure to wind farm sound. *Health Psychol*. 2013.	Mechanistic Evidence	Experimental study of expectations to wind farm sound
Crichton F, Dodd G, Schmid G, Gamble G, Petrie KJ. Can expectations produce symptoms from infrasound associated with wind turbines? *Health Psychol*. 2014;33(4):360-4.	Mechanistic Evidence	Double blind study of infrasound in university students

CITATIONS OF SUBMITTED LITERATURE	**CATEGORY**	**REASON**
Cummings J. The variability factor in wind turbine noise. 5th International Conference on Wind Turbine Noise 28 - 30 August 2013; Denver.	Exclude	Conference abstract
Dadali VA, Svidovyĭ VI, Makarov VG, Gor'kova LB, Kuleva VA, Pavlova RN, Tarasova OV, Timofeeva VM. [Effects of infrasound and protective effect ofadaptogens in experimental animals]. *Gig Sanit*. 1992 Jan;(1):40-3. Russian.	Exclude	Not publicly available in English; animal study
David A, Thorne B. Underpinning methodology to derive stand-off distances from a wind farm. 20th International Congress on Sound & Vibration; 7-11 July 2013; Bangkok, Thailand.	Exclude	Not based on new (or new analysis of) systematically collected data
Deignan B, Harvey E, Hoffman-Goetz L. [RS] Fright factors about wind turbines and health in Ontario newspapers before and after the Green Energy Act. Health, *Risk & Society* 2013;15(3).	Exclude	Not based on new (or new analysis of) systematically collected data, as based on newspaper reports
DeLacy PB, McCann M. Wind projects and land value. 2012.	Exclude	Not based on new (or new analysis of) systematically collected data
Delaney JA, Suissa S. The case-crossover study design in pharmacoepidemiology. *Statistical Methods in Medical Research*. 2009;18(1):53-65.	Exclude	Not relevant to exposure to wind farm emissions and not based on new (or new analysis of) systematically collected data
den Tandt A. Wind Turbine Syndrome: Is infrasound the cause? *The Daily Observer*. 2011.	Exclude	Newspaper article; not based on new (or new analysis of) systematically collected data
Dept Health Victoria. Wind farms, sound and health: Community information. Melbourne: Department of Health of Victoria, 2013.	Exclude	Guidelines; not based on new (or new analysis of) systematically collected data
Dept Health Victoria. Wind farms, sound and health: Technical information. Melbourne: Department of Health of Victoria, 2013.	Exclude	Guidelines; not based on new (or new analysis of) systematically collected data
Devine-Wright P. Beyond NIMBYism: towards an integrated framework for understanding public perceptions of wind energy. *Wind Energy*. 2005;8:125-39.	Exclude	Not based on new (or new analysis of) systematically collected data
Doolan C, Moreau D. [RS] An on-demand simultaneous annoyance and indoor noise recording technique. *Acoustics Aust*. 2013;41(2):141-45.	Background Evidence	Paper presenting a new annoyance and noise monitoring technique
Doolan CJ, Moreau DJ, Brooks L. Wind turbine noise mechanisms and some concepts for its control. *Acoustics Aust*. 2012;40(1):7-13.	Exclude	Not based on new (or new analysis of) systematically collected data
Doolan CJ. A review of wind turbine noise perception, annoyance and low frequency emission. *Wind Engineering*. 2013;37(1):97-104.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected data or analysis.
Enbom H, Enbom I. Infrasound from wind turbines - an overlooked health risk. *Swedish Med J*. 2013;110:1388-89.	Exclude	Commentary; not based on new (or new analysis of) systematically collected data

CITATIONS OF SUBMITTED LITERATURE	CATEGORY	REASON
Engineering H. Low frequency noise and infrasound associated with wind turbine generation systems, A literature review. Ontario Ministry of Environment, 2010.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected data
enHealth. The health effects of environmental noise - other than hearing loss. Commonwealth of Australia, 2004.	Exclude	Not based on new (or new analysis of) systematically collected data
Environment Protection Authority SA. Waterloo Wind Farm environmental noise study. 2013.	Background Evidence	Noise survey
Erickson v. Ministry of the Environment Environmental Decision Case Nos 10-121, 10-122. Environmental Review Tribunal; 2011.	Exclude	Legal case; not based on new (or new analysis of) systematically collected data
European Wind Energy Technology Platform. Strategic research agenda market deployment strategy from 2008 to 2030. Annex B: State-of-the-art and current insufficiencies. 2008.	Exclude	Not based on new (or new analysis of) systematically collected data
Evans A. Wind farms and health. 2014.	Exclude	Opinion piece; not based on new (or new analysis of) systematically collected data
Evans T, Cooper J, Lenchine V. Infrasound levels near windfarms and in other environments. Environment Protection Authority South Australia, 2013.	Exclude	Already considered and either included or excluded from the Independent Review
Evans T [Resonate Acoustics]. Macarthur Wind Farm, Infrasound & Low Frequency Noise, Operational Monitoring Results. Prepared for AGL Energy Limited 2013.	Background Evidence	Wind turbine noise monitoring survey
Falmouth Health Department. Letter to Massachusetts Department of Public Health. 2012.	Exclude	Letter; not based on new (or new analysis of) systematically collected data
Farboud A, Crunkhorn R, Trinidade A. [RS] 'Wind turbine syndrome': fact or fiction? *J Laryngol Otol*. 2013;127(3):222-6.	Exclude	Narrative review with no analysis of results and no evidence on likely level of exposure to wind farm emissions
Gabriel J, Vogl S. Amplitude modulation and complaints about wind turbine noise. 5th International Conference on Wind Turbine Noise 28 - 30 August 2013; Denver.	Exclude	Conference abstract
Gardner A, Statement to VCAT Cherry Tree Hearing: Hearing before the Victorian Civil Administrative Tribunal (24 October, 2013).	Exclude	Legal proceedings; not based on new (or new analysis of) systematically collected data
Glegg S, Baxter SM, Glendinning AG. The prediction of broadband noise from wind turbines. *J Sound Vibration*. 1987;118(2):217-39.	Exclude	Testing a prediction model, so not based on new (or new analysis of) systematically collected data
Grosveld F. Prediction of broadband noise from horizontal axis wind turbines. *J Propulsion Power*. 1985;1(4):292-99.	Exclude	Testing a prediction model, so not based on new (or new analysis of) systematically collected data

CITATIONS OF SUBMITTED LITERATURE	CATEGORY	REASON
Hanning CD, Evans A. Wind turbine noise. *BMJ.* 2012;344:e1527.	Exclude	Already considered and either included or excluded from the Independent Review
Hansen K, Henrys N, Hansen C, Doolan C, Moreau D. Wind farm noise -what is a reasonable limit in rural areas? Acoustics 2012; 21-23 November 2012; Fremantle, Western Australia.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected data, no analysis of results
Harrison J. Wind turbine noise. *Bull Sci Technol Soc*. 2011;31:256.	Exclude	Already considered and either included or excluded from the Independent Review
Harry A. Wind turbines, noise and health: Self published; 2007.	Exclude	Not based on new (or new analysis of) systematically collected data
Havas M, Colling D. Wind turbines make waves: Why some residents near wind turbines become ill. *Bull Sci Technol Soc*. 2011;31:414.	Exclude	Not based on new (or new analysis of) systematically collected data
Hayes-Mackenzie. Report on wind farms (Drafts 1 and 3). 2006.	Exclude	Not based on new (or new analysis of) systematically collected data.
Health and Welfare Canada. Achieving health for all: A framework for health promotion. 1986.	Exclude	Guidelines; not based on new (or new analysis of) systematically collected data
Health Canada. Community noise annoyance. 2005.	Exclude	Fact sheet; not based on new (or new analysis of) systematically collected data
Health Canada. Health Canada wind turbine noise and health study design consultation. 2014; Available from: http://www.hc-sc.gc.ca/ewh-semt/consult/_2013/wind_turbine-eoliennes/index-eng.php.	Exclude	Not based on new (or new analysis of) systematically collected data
Higgins J. Wind farms: A blessing or a scam. *The Australian*. 4 May 2012.	Exclude	Newspaper article; not based on new (or new analysis of) systematically collected data
Howe Gastmeier Capnik Ltd [HGC Engineering]. Wind turbines and sound: Review and best practice guidelines. Prepared for the Canadian Wind Energy Association, 2007.	Exclude	Guidelines; not based on new (or new analysis of) systematically collected data
Horner B, Jeffery RD, Krogh CME. Literature reviews on wind turbines and health: Are they enough? *Bull Sci Technol Soc*. 2011;31:339.	Exclude	Already considered and either included or excluded from the Independent Review
Horner B, Krogh CME, Jeffery RD. Audit report: literature reviews on wind turbine noise and health. 5th International Conference on Wind Turbine Noise 28 - 30 August 2013; Denver.	Exclude	Conference abstract
Howe Gastmeier Chapnik Limited. Low frequency noise and infrasound associated with wind turbine generator systems: A literature review. Mississauga, Ontario, Canada: Ministry of the Environment, 2010.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected data

CITATIONS OF SUBMITTED LITERATURE	**CATEGORY**	**REASON**
Hubbard H. Noise induced house vibrations and human perception. *Noise Control Engineer J*. 1982;19(2):49-55.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected data
Huson L. Expert Evidence at VCAT Cherry Tree Hearing: Hearing before the Victorian Civil Administrative Tribunal (24 October, 2013).	Exclude	Legal proceedings; not based on new (or new analysis of) systematically collected data
Huson L. Amplitude modulation case study at the Leonards Hill Wind Farm, Victoria, Australia. Institute of Acoustics meeting, Wind Turbine Noise; 20 March 2014; Newport, Wales.	Exclude	Only one dwelling, so not based on new (or new analysis of) systematically collected or analysed data
Iser D. Survey on wind power station effects. Submission to NHMRC. 2004.	Exclude	Already considered and either included or excluded from the Independent Review
Ising H, Braun C. Acute and chronic endocrine effects of noise: Review of the research conducted at the Institute for Water, Soil and Air Hygiene. *Noise Health*. 2000;2(7):7-24.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected data
Jakobsen J. Infrasound emission from wind farms. *J Low Freq Noise V A*. 2005;24(3):145-55.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected data
James R. Wind turbine infra and low-frequency sound: Warnings signs that were not heard. *Bull Sci Technol Soc*. 2012;32 no. 2 (2):108-27.	Exclude	Not based on new (or new analysis of) systematically collected data
Janssen S, Vos H, Eisses A, Pedersen E. A comparison between exposure-response relationships for wind turbine annoyance and annoyance due to other noise sources. *J Acoust Soc Am. 2011*;130(6):3746.	Direct Evidence	Excluded from the Independent Review, but reconsidered at request of the Reference Group.
Jeffery RD, Krogh CME, Horner B. [RS] Adverse health effects of industrial wind turbines. *Can Fam Phys*. 2013;59:921-25.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected data
Jeffery RD, Krogh CME, Horner B. Adverse health effects of industrial wind turbines [Letter to the editor]. *Can Fam Phys*. 2013;59:921-25.	Exclude	Letter; not based on new (or new analysis of) systematically collected data
Jeffery RD, Krogh CME, Horner B. Industrial wind turbines and adverse health effects. *Can J Rural Med*. 2014;19(1):21-6.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected data
Kaiser S, Fröhlingsdorf M. Wuthering heights: The dangers of wind power. *New York Times*. 2007.	Exclude	Newspaper article; not based on new (or new analysis of) systematically collected data
Katayama N, Takata G, Miyake M, Nanahara T. Theoretical study on synchronization phenomena of wind turbines in a wind farm. *Elec Engineer Japan*. 2006;155:9-18.	Exclude	Not based on new (or new analysis of) systematically collected data
Keith SE, Michaud DS, Bly SHP. A proposal for evaluating the potential health effects of wind turbine noise for projects under the Canadian Environmental Assessment Act. *J Low Freq Noise V A*. 2008;27:253-65.	Exclude	Already considered and either included or excluded from the Independent Review

CITATIONS OF SUBMITTED LITERATURE	CATEGORY	REASON
Kelley N. A proposed metric for assessing the potential of community annoyance from wind turbine low-frequency noise emissions. Windpower '87 Conference and Exposition; October 5-8, 1987; San Francisco.	Mechanistic Evidence	Laboratory study with sound simulations
Kelley ND, Hemphill RR, McKenna HE. Methodology for assessment of wind turbine noise generation. *J Solar Energy Engineering*. 1982;104:112-20.	Exclude	Narrative review of a measurement method, not based on new (or new analysis of) systematically collected data
Kelley ND, McKenna HE, Hemphill RR, Etter CL, Garrelts RL, Linn NC. Acoustic noise associated with the MOD-1 Wind Turbine: Its source, impact, and control Colorado: Solar Energy Research Institute, 1985.	Exclude	Extensive measurements of two wind turbines in response to complaints; questionable whether based on new (or new analysis of) systematically collected data
Knopper LD, Ollson CA. Health effects and wind turbines: a review of the literature. *Environ Health*. 2011;10:78.	Exclude	Already considered and either included or excluded from the Independent Review
Krogh C. Industrial wind turbine development and loss of social justice? *Bull Sci Technol Soc*. 2011;31:321.	Exclude	Not based on new (or new analysis of) systematically collected data
Krogh CME, Gillis L, Kouwen N, Aramini J. WindVOiCe, a self-reporting survey: Adverse health effects, industrial wind turbines, and the need for vigilance monitoring. *Bull Sci Technol Soc*. 2011;31:334.	Exclude	Already considered and either included or excluded from the Independent Review
Krogh CME, Jeffery RD, Aramini J, Horner B. Annoyance can represent a serious degradation of health: wind turbine noise a case study. Inter-noise 2012; 19-22 August 2002; New York City, NY.	Exclude	Not based on new (or new analysis of) systematically collected data
Krogh CME, Jeffery RD, Aramini J, Horner B. Wind turbine noise perception, pathways and effects: a case study. Inter-noise 2012; 19-22 August 2002; New York City, NY.	Exclude	Not based on new (or new analysis of) systematically collected data
Krogh CME, Jeffery RD, Aramini J, Horner B. Wind turbines can harm humans: a case study. Inter-noise 2012; 19-22 August 2002; New York City, NY.	Exclude	Not based on new (or new analysis of) systematically collected data
Krogh CME, Morris J, May M, Papadopoulos G, Horner B. Trading off human health: Wind turbine noise and government policy. 5th International Conference on Wind Turbine Noise 28-30 August 2013; Denver.	Exclude	Conference abstract
Krogh CME. Open submission: Risk of harm to children and industrial wind turbines. Health and social-economic impacts in Canada, Health Canada Wind Turbine Noise and Health Study. 2012.	Exclude	Not based on new (or new analysis of) systematically collected data
Kuwano S, Yano H, Kageyama T. Social survey on community response to wind turbine noise in Japan. 42nd International Congress and Exposition on Noise Control Engineering; 15-18 September 2013; Innsbruck, Austria.	Direct Evidence	Survey of annoyance related to wind turbine noise

CITATIONS OF SUBMITTED LITERATURE	**CATEGORY**	**REASON**
Lansink B. Case studies regarding 230kV and a 500kV industrial high voltage electrical power transmission corridors located in Ontario, Canada. Prepared by Lansink Appraisers and Consulting 2013.	Exclude	Not based on new (or new analysis of) systematically collected data
Lansink B. Case study, diminution in value, wind turbine analysis. Prepared by Lansink Appraisers and Consulting, 2012.	Exclude	Not based on new (or new analysis of) systematically collected data
Laratro A, Arjomandi M, Kelso R, Cazzolato B. A discussion of wind turbine interaction and stall contributions to wind farm noise. *J Wind Engin Industr Aerodynam*. 2014;127:1-10.	Exclude	Not based on new (or new analysis of) systematically collected data
Laurie S. A critical analysis of accuracy of the “complaints” data from the Chapman et al “nocebo” research. 2013.	Exclude	Not based on new (or new analysis of) systematically collected data
Leake J, Byford H. Officials cover up wind farm noise report. *The Sunday Times*. 13 December 2009.	Exclude	Newspaper article; not based on new (or new analysis of) systematically collected data
Leventhall G. Development of a course in computerised cognitive behavioral therapy aimed at relieving the problems of those suffering from noise exposure, in particular, exposure to low frequency noise (NANR 237). Queen’s Printer and Controller of HMSO, 2007.	Exclude	Not based on new (or new analysis of) systematically collected data
Leventhall G. Infrasound from wind turbines: Fact, fiction or deception. *Canadian Acoustics*. 2006;34:29-36.	Exclude	Not based on new (or new analysis of) systematically collected data
Leventhall G. Wind farms and human health. Presentation to NHMRC Scientific Forum. 2011.	Exclude	Conference presentation
Leventhall G. Wind turbines large small and unusual. 2009.	Exclude	Not based on new (or new analysis of) systematically collected data
Leventhall HG, Pelmear P, Benton S. A review of published research on low frequency noise and its effects. Department for Environment, Food and Rural Affairs, 2003.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected data
Leventhall HG. Low frequency noise and annoyance. *Noise Health*. 2004;6:59-72.	Exclude	Not based on new (or new analysis of) systematically collected data
Leventhall HG. Wind turbine syndrome: An appraisal. Testimony before the Public Service Commission of Wisconsin (PSC Ref#121877 20). 2010.	Exclude	Legal case; not based on new (or new analysis of) systematically collected data
Lichtenhan JT, Salt AN. Amplitude modulation of audible sounds by non-audible sounds: understanding the effects of wind turbine noise. *J Acoust Soc Am*. 2013;133(5):3419.	Exclude	Animal study
Makarewicz R. Thump noise prediction. 5th International Conference on Wind Turbine Noise 28 - 30 August 2013; Denver.	Exclude	Conference abstract

CITATIONS OF SUBMITTED LITERATURE	CATEGORY	REASON
Maschke C, Niemann A. Health effects of annoyance induced by neighbour noise. *Noise Control Engineer J*. 2007;55:348-56.	Background Evidence	Analysis of self-reported annoyance from neighbour noise
Massachusetts Dept of Health. Wind turbine health impact study: Report of independent expert panel. Massachusetts Department of Environmental Protection, Massachusetts Department of Public Health, 2012.	Exclude	Not based on new (or new analysis of) systematically collected data
McBride D, Shepherd D, Welch D. A longitudinal study of the impact of wind turbine proximity on health related quality of life. 42nd International Congress and Exposition on Noise Control Engineering; 15-18 September 2013; Innsbruck, Austria.	Direct Evidence	Study of health-related quality of life in a community living near a wind turbine
McMurtry RY. Toward a case definition of adverse health effects in the environs of industrial wind turbines: Facilitating a clinical diagnosis. *Bull Sci Technol Soc*. 2011;31:316.	Exclude	Not based on new (or new analysis of) systematically collected data
McSwiggan D, Litttler T, Morrow D, Kennedy J. A study of tower shadow effect on fixed-speed wind turbines. Universities Power Engineering Conference; Padova 2008.	Exclude	Relevant to wind turbine performance rather than human exposures to wind farm noise or health outcomes
Michaud DS, Keith SE, McMurchy D. Noise annoyance in Canada. *Noise Health*. 2005;7(27):39-47.	Exclude	Not relevant to noise exposure
Mikołajczak J, Borowski S Marć-Pieńkowska J, Odrowąż-Sypniewska G, Bernacki Z, Siódmiak J, et al. Preliminary studies on the reaction of growing geese (Anser anser f. domestica) to the proximity of wind turbines. *Polish J Vet Sci*. 2013;16(4):679-86.	Exclude	Animal study
Minnesota Department of Health. Public health impacts of wind turbines. 2009.	Exclude	Not based on new (or new analysis of) systematically collected data
Møller H, Pedersen C. Low-frequency noise from large wind turbines. *J Acoust Soc Am*. 2011;129(6):3727-44.	Background Evidence	Noise survey of small and large wind turbines
Moller-Levet CS, Archer SN, Bucca G, Laing EE, Slak A, Kabiljo R, et al. Effects of insufficient sleep on circadian rhythmicity and expression amplitude of the human blood transcriptome. *Proc Natl Acad Sci USA*. 2013;110(12):E1132-41.	Exclude	Laboratory study; no evidence on exposures relevant to wind turbines; no Mechanistic and no Parallel data
Morris M. A comparison of wind turbine acoustic measurements and analysis, resident responses and wind farm power output during on-off testing at a South Australia wind farm. 2014.	Exclude	One wind turbine, so not based on new (or new analysis of) systematically collected data
Morris M. Waterloo case series preliminary report. 2013.	Exclude	Data from 2012 survey already included in Independent Review
Mroczek B, Kurpas D, Karakiewicz B. [RS] Influence of distances between places of residence and wind farms on the quality of life in nearby areas. *Ann Agric Environ Med*. 2012;19(4):692-6.	Direct Evidence	Identified as Direct Evidence in the updated literature search

CITATIONS OF SUBMITTED LITERATURE	**CATEGORY**	**REASON**
Munzel T, Gori T, Babisch W, Basner M. Cardiovascular effects of environmental noise exposure. *Eur Heart J*. 2014;35(13):829-36.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected or analysed data
National Research Council. Environmental impacts of wind-energy projects. Washington DC: National Academies Press; 2007.	Exclude	Narrative review concerned with environmental impacts
Navarette LM. Behavioral effects of wind farms on wintering sandhill cranes (Grus canadensis) on the Texas high plains [Thesis for the degree of Master of Science]: Texas Tech University; 2011.	Exclude	Animal study
Navarrete LM, Griffis-Kyle K, editors. Sandhill Crane (Grus canadensis) collisions with wind turbines in the Southern High Plains of Texas. North American Crane Workshop; in review.	Exclude	Animal study
NIEHS. Infrasound brief review of toxicological literature. National Institutes of Environmental Health Sciences, 2001.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected or analysed data
Niemann H, Bonnefoy X, Braubach M, Hecht K, Maschke C, Rodrigues C, et al. Noise-induced annoyance and morbidity results from the pan-European LARES study. *Noise Health*. 2006;8(31):63-79.	Exclude	No evidence on the likely level of exposure to emissions produced by wind farms
Nishimura K. The effects of infrasound on pituitary adreno-cortical response and gastric microcirculation in rats. *Journal of Low Frequency Noise and Vibration*. 1988;7(1):20-33.	Exclude	Animal study
Nissenbaum M, Aramini J, Hanning C. Adverse health effects of industrial wind turbines: A preliminary report. 10th International Congress on Noise as a Public Health Problem (ICBEN); 24-28 July 2011; London, UK.	Exclude	Already considered and either included or excluded from the Independent Review
Nissenbaum M. Letter to Secretary, Senate Environment & Communications committee inquiry into the renewable energy (wind farm noise) bill. 2012.	Exclude	Letter; not based on new (or new analysis of) systematically collected data
Nissenbaum MA, Aramini JJ, Hanning CD. Effects of industrial wind turbine noise on sleep and health. *Noise Health*. 2012;14(60):237-43.	Exclude	Already considered and either included or excluded from the Independent Review
NSW Dept Planning and Infrastructure. Major project assessment: Bodangora Wind Farm, Bodangora Central Western NSW MP10_0157. Sydney: 2013.	Exclude	Not based on new (or new analysis of) systematically collected data
NSW Dept Planning and Infrastructure. Major project assessment: Collector Wind Farm, Upper Lachlan Shire NSW Southern Tablelands MP10_0156. Sydney: 2013.	Exclude	Not based on new (or a new analysis of) systematically collected data
NSW Planning Assessment Commission. NSW Planning Assessment Commission determination report: Bodangora Wind Farm Project, Wellington LGA. Sydney: 2013.	Exclude	Not based on new (or new analysis of) systematically collected data
O'Sullivan C. Warning over wind turbine syndrome - Irish Deputy Chief Health Officer. Irish Examiner. 3 March 2014.	Exclude	Fact sheet; not based on new (or new analysis of) systematically collected data

CITATIONS OF SUBMITTED LITERATURE	CATEGORY	REASON
Oerlemans S, Sijtsma P, Mendez Lopez B. Location and quantification of noise sources on a wind turbine. *J Sound Vibration*. 2007;299(4):869-83.	Exclude	Relevant to wind turbine performance rather than human exposures to wind farm noise or health outcomes
Oerlemans S. An explanation for enhanced amplitude modulation of wind turbine noise. Work Package A1. Renewable Energy, U.K. Wind turbine amplitude modulation: Research to improve understanding as to its cause and effect: Renewable Energy UK; 2013.	Exclude	Relevant to wind turbine performance rather than human exposures to wind farm noise or health outcomes
Ollson CA, Knopper LD, McCallum LC, Whitfield-Aslund ML. [RS] Are the findings of "Effects of industrial wind turbine noise on sleep and health" supported? *Noise Health*. 2013;15(63):148-50.	Exclude	Letter; not based on new (or new analysis of) systematically collected data
Oman C, Paloski WH, Young LR. In Memoriam F. Owen Black, M.D. *J Vestibular Res*. 2012;22:56.	Exclude	Not based on new (or new analysis of) systematically collected data
Paller C. Exploring the association between proximity to industrial wind turbines and self-reported health outcomes in Ontario, Canada: University of Waterloo; 2014.	Direct Evidence	Masters Thesis; association between proximity to wind turbines and self-reported health effects
Paller C, Bigelow P, Majowicz S, Law J, Christidis T. Wind turbine noise, sleep quality, and symptoms of inner ear problems. Poster. Symposium on Sustainability; 17 October; York University, Toronto, 2013.	Exclude	Duplicate data. Poster based on Science Masters Thesis by Paller C.
Pedersen E, Bakker R, Bouma J, van den Berg F. Response to noise from modern wind farms in the Netherlands. *J Acoust Soc Am*. 2009;126:634-43.	Exclude	Already considered and either included or excluded from the Independent Review
Pedersen E, Persson Waye K. Wind turbine noise, annoyance and self-reported health and well-being in different living environments. *Occup Environ Med*. 2007;64(7):480-86.	Exclude	Already considered and either included or excluded from the Independent Review
Pedersen E, Persson-Waye K. Perception and annoyance due to wind turbine noise--a dose-response relationship. *J Acoust Soc Am*. 2004;116(6):3460-70.	Exclude	Already considered and either included or excluded from the Independent Review
Persinger M. Infrasound, human health and adaptation: An integrative overview of recondite hazards in a complex environment. *Nat Hazards*. 2014;70(1):501-25.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected or analysed data
Persson Waye K, Bengtsson J, Kjellberg A, Benton S. Low frequency noise "pollution" interferes with performance. *Noise Health*. 2001;4(13):33-49.	Parallel Evidence	Experimental study of low frequency noise on cognitive performance and annoyance
Persson Waye K, Rylander R, Benton S, Leventhall HG. Effects on performance and work quality due to low frequency ventilation noise. *J Sound Vibration*. 1997;205(4):467-74.	Parallel Evidence	Laboratory pilot exposure study of 50 students
Persson-Waye K, Clow A, Edwards S, Hucklebridge F, Rylander R. Effects of nighttime low frequency noise on the cortisol response to awakening and subjective sleep quality. *Life Sci*. 2003;72:863-75.	Exclude	Already considered and either included or excluded from the Independent Review

CITATIONS OF SUBMITTED LITERATURE	CATEGORY	REASON
Phillips C. Properly interpreting the epidemiologic evidence about the health effects of industrial wind turbines on nearby residents. *Bull Sci Technol Soc*. 2011;31:303.	Exclude	Not based on new (or new analysis of) systematically collected data
Phipps R, Amati M, McCoard S, Fisher R. Visual and noise effects reported by residents living close to Manawatu wind farms: Preliminary survey results. 2007.	Exclude	Already considered and either included or excluded from the Independent Review
Pierpont N. Wind turbine syndrome and the brain. First International Symposium on the Global Wind Industry & Adverse Health Effects: Loss of Social Justice?; 30 October 2010; Picton, Ontario, Canada.	Exclude	Full conference paper; narrative review not based on new (or new analysis of) systematically collected or analysed data
Pierpont N. Wind turbine syndrome: a report on a natural experiment. Santa Fe, New Mexico: K-Selected Books; 2009.	Exclude	Already considered and either included or excluded from the Independent Review
PINCHE. Report WP7 Summary PINCHE policy recommendations. Policy Interpretation Network on Children's Health and Environment, 2002.	Exclude	Policy recommendations; not based on new (or new analysis of) systematically collected data
Pohl J, Faul F. Belästigung durch periodischen Schattenwurf von Windenergieanlagen. Kiel, Germany: Institut für Psychologie der Christian-Albrechts-Universität zu Kiel, 1999.	Exclude	Not in English
Portuguese Supreme Court ruling on wind turbines in Quinta. 2013.	Exclude	Legal proceedings; not based on new (or new analysis of) systematically collected data
Proceedings of the Fourth International Meeting on Wind Turbine Noise. Fourth International Meeting on Wind Turbine Noise; 2011; Rome, Italy.	Exclude	Whole conference proceedings; no specific abstract
Punch J, James R, Pabst D. Wind-turbine noise: what audiologists should know. *Audiology Today*. 2010;July/August:20-31.	Exclude	Not based on new (or new analysis of) systematically collected data
Punch J. Review of Crichton et al 2013.	Exclude	Commentary on a published paper; not based on new (or new analysis of) systematically collected data
Qibai C, Shi H. Technical contribution: An investigation on the physiological and psychological effects of infrasound on persons. *J Low Freq Noise, Vibr Active Control*. 2004;23(1):71-6.	Background Evidence	Laboratory study in university students
QLD Health. Coal seam gas in the Tara region: Summary risk assessment of health complaints and environmental monitoring data. 2013.	Exclude	Not based on new (or new analysis of) systematically collected data
Rand RW, Ambrose SE, Krogh CME. Occupational health and industrial wind turbines: A case study. *Bull Sci Technol Soc*. 2011;31:359.	Exclude	Not based on new (or new analysis of) systematically collected data
Reider S. Testimony Senate Energy and Natural Resources Committee.	Exclude	Legal proceedings; not based on new (or new analysis of) systematically collected data

CITATIONS OF SUBMITTED LITERATURE	CATEGORY	REASON
Richarz W, Richarz H, Gambino T. Correlating very low frequency sound pulse to audible wind turbine sound. Fourth International Meeting on Wind Turbine Noise; 12-14 April 2011; Rome, Italy.	Exclude	Conference abstract
Robinson S. Mental health impacts of coal seam gas mining (a personal view). Submission to Inquiry into Coal Seam gas, NSW. 2011.	Exclude	Not based on new (or new analysis of) systematically collected data
Rushforth I, Moorhouse A, Styles P. A case study of low frequency noise assessed using DIN 45680 criteria. *J Low Freq Noise, Vibr Active Control*. 2002;21(4):181-98.	Exclude	Case study, not based on new (or new analysis of) systematically collected data
Salt AN, Hullar TE. Responses of the ear to low frequency sounds, infrasound and wind turbines. *Hear Res*. 2010;268(1-2):12-21.	Exclude	Narrative review; no evidence on noise or other emissions from wind turbines
Salt AN, Kaltenbach JA. Infrasound from wind turbines could affect humans. *Bull Sci Technol Soc*. 2011;31:296.	Exclude	Not based on new (or new analysis of) systematically collected data
Salt AN, Lichtenhan J. How does wind turbine noise affect people? *Acoustics Today*. 2014;10(1):20-8.	Exclude	Not based on new (or new analysis of) systematically collected data
Salt AN, Lichtenhan J. Perception-based protection from low-frequency sounds may not be enough. Inter-noise 2012; 19-22 August; New York City, NY.	Exclude	Animal study
Salt AN, Lichtenhan J. Responses of the ear to low frequency sounds, infrasound and wind turbines. Fourth International Meeting on Wind Turbine Noise; 12-14 April 2011; Rome, Italy.	Exclude	Narrative paper; not based on new (or new analysis of) systematically collected data
Salt AN, Lichtenhan JT, Gill RM, JJ. H. Large endolymphatic potentials from low-frequency and infrasonic tones in the guinea pig. *J Acoust Soc Am*. 2013;133:1561-71.	Exclude	Animal study
Salt AN. Can wind turbines be bad for you? Undated.	Exclude	Not based on new (or new analysis of) systematically collected data
Salt AN. Industrial wind farms generate infrasound. 2010; Available from: http://oto2.wustl.edu/cochlea/wt1.html.	Exclude	Not based on new (or new analysis of) systematically collected and analysed data
Schafer A. Macarthur wind energy facility preliminary survey. 2013.	Exclude	Not based on new (or new analysis of) systematically collected data
Schneider P. Cullerin Range Wind Farm Survey 2012.	Exclude	Not based on new (or new analysis of) systematically collected data
Schneider P. Cullerin Range Wind Farm Survey follow-up survey July - August 2013.	Exclude	Not based on new (or new analysis of) systematically collected data

CITATIONS OF SUBMITTED LITERATURE	CATEGORY	REASON
Schomer P, editor. Can wind turbine sound that is below the threshold of hearing be heard? *Proceedings of Meetings on Acoustics*; 2013: Acoustical Society of America.	Exclude	Not based on new (or new analysis of) systematically collected data
Schomer P, Erdreich J, Boyle J, Pamidighantam P. A proposed theory to explain some adverse physiological effects of the infrasonic emissions at some wind farm sites. 5th International Conference on Wind Turbine Noise 28-30 August 2013; Denver.	Background Evidence	Full conference paper with some systematically collected noise data [Secondary publication to Walker 2012]
Schomer P, Parmidighantam P. A critical analysis of: wind turbine health impact study. Report of independent expert panel. *J Acoust Soc Am*. 2013;134:4096.	Exclude	Not based on new (or new analysis of) systematically collected data
SEDA. NSW wind atlas. Undated.	Exclude	Not based on new (or new analysis of) systematically collected data of relevance to wind turbine emissions or outcomes
Seltenrich N. [RS] Wind turbines: a different breed of noise? *Env Health Perspectives*. 2014;122(1).	Exclude	Not based on new (or new analysis of) systematically collected data
Seong Y, Lee S, Gwak DY, Cho Y, Hong J, Lee S. An experimental study on rating scale for annoyance due to wind turbine noise. 42nd International Congress and Exposition on Noise Control Engineering; 15-18 September 2013; Innsbruck, Austria.	Exclude	Laboratory study of wind turbine noise; validating noise metrics
Shain M. Public health ethics, legitimacy, and the challenges of industrial wind turbines: the case of Ontario, Canada. *Bull Sci Technol Soc*. 2011;31:256.	Exclude	Not based on new (or new analysis of) systematically collected data
Shepherd D, Billington R. Mitigating the acoustic impacts of modern technologies: Acoustic, health, and psychosocial factors informing wind farm placement. *Bull Sci Technol Soc*. 2011;31:389.	Exclude	Narrative paper; no evidence on noise or other emissions from wind turbines
Shepherd D, Hanning C, Thorne B. Windfarms. In: Jørgensen S, editor. Encyclopedia of environmental management: Taylor & Francis; 2012.	Exclude	Not based on new (or new analysis of) systematically collected data
Shepherd D, Mcbride D, Welch D, Dirks KN, Hill E. Wind turbine noise and health-related quality of life of nearby residents: a cross sectional study in New Zealand. Fourth International Meeting on Wind Turbine Noise; 12-14 April 2011; Rome, Italy.	Exclude	Duplicate of data already included in Independent Review
Shepherd D, McBride D, Welch D, Dirks KN, Hill EM. Evaluating the impact of wind turbine noise on health-related quality of life. *Noise Health*. 2011;13(54):333-9.	Exclude	Already considered and either included or excluded from the Independent Review
Shepherd D, Welch D, Dirks KN, McBride D. Do quiet areas afford greater health-related quality of life than noisy areas? *Int J Environ Res Pub Health*. 2013;10(4):1284-303.	Exclude	Wind turbine and outcome findings all taken from Shepherd 2011, which was included in the Independent Review

CITATIONS OF SUBMITTED LITERATURE	CATEGORY	REASON
Siponen D. Noise annoyance of wind farms. Research report VTT-R-00951-11. Technical Research Centre of Finland, 2011.	Exclude	Narrative paper; not based on new (or new analysis of) systematically collected data
Smith MG, Croy I, Ogren M, Persson Waye K. On the influence of freight trains on humans: a laboratory investigation of the impact of nocturnal low frequency vibration and noise on sleep and heart rate. *PloS One*. 2013;8(2):e55829.	Parallel Evidence	Laboratory study of six subjects: noise and vibration
Standing Senate Committee on Social Affairs SaT. A healthy, productive Canada: A determinant of health approach. Ottawa, Canada: Senate, 2009.	Exclude	Committee report; not based on new (or new analysis of) systematically collected data
Stantec Consulting Ltd. Health effects and wind turbines: A review for renewable energy approval (REA) applications submitted under Ontario Regulation 359/09. 2011.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected data
Stantec Consulting Ltd. Ostrander Point wind energy design and operations report. Gilead Power Corporation, 2010.	Exclude	Operations report; not based on new (or new analysis of) systematically collected data of relevance to wind farm emissions or outcomes
Stigwood M, Large S, Stigwood D. Audible amplitude modulation - results of field measurements and investigations compared to psycho-acoustical assessment and theoretical research. 5th International Conference on Wind Turbine Noise 28-30 August 2013; Denver.	Exclude	Conference abstract
Styles P, Simpson I, Toon S, England R, Wright M. Microseismic and infrasound monitoring of low frequency noise and vibrations from wind farms - Recommendations on the siting of wind farms in the vicinity of Eskdalemuir, Scotland. Keele, Staffordshire UK: Applied and Environmental Geophysics Research Group, Earth Sciences and Geography, School of Physical and Geographical Sciences, Keele University, 2005.	Background Evidence	Systematically collected wind farm noise data
Superior Court, Falmouth Massachusetts Preliminary Injunction. 2013.	Exclude	Legal proceedings; not based on new (or new analysis of) systematically collected data
Suter AH. Noise and its effects. Administrative Conference of the United States, 1991.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected data
Swinbanks M. Peer review of Crichton et al 2013. 2013.	Exclude	Not based on new (or new analysis of) systematically collected data
Swinbanks MA. Numerical simulation of infrasound perception, with reference to prior reported laboratory effects. Inter-noise 2012; 19-22 August; New York City, NY.	Exclude	Simulation study; not systematically collected wind farm emission data
Tachibana H, Yano H, Sakamoto S. Nationwide field measurements of wind turbine noise in Japan. 42nd International Congress and Exposition on Noise Control Engineering; 15-18 September 2013; Innsbruck, Austria.	Exclude	Wind turbine noise survey in Japan (cannot obtain full article). [Appears to be linked to Yano study]

CITATIONS OF SUBMITTED LITERATURE	CATEGORY	REASON
Taylor J, Eastwick C, Lawrence C, Wilson R. Noise levels and noise perception from small and micro wind turbines. *Renewable Energy*. 2013;55:120-27.	Mechanistic Evidence	Small postal survey of residents around wind turbines
Taylor J, Eastwick C, Wilson R, C L. The influence of negative oriented personality traits on the effects of wind turbine noise. *Personality and Individual Differences*. 2013;54(3):338-43.	Direct Evidence	Identified as Direct Evidence in the updated literature search
Tharpaland International Retreat Centre. Three wind farm studies and an assessment of infrasound. Submission to the Inquiry into Scottish Government's Renewables Targets 2012.	Exclude	Not based on new (or new analysis of) systematically collected data
Thorne B, Shepherd D. Quiet as an environmental value: A contrast between two legislative approaches. *Int J Environ Res Pub Health*. 2013;10(7):2741-59.	Exclude	Not based on new (or new analysis of) systematically collected data
Thorne B. The problems with ''noise numbers'' for wind farm noise assessment. *Bull Sci Technol Soc*. 2011;31:262.	Exclude	Already considered and either included or excluded from the Independent Review
Thorne B. Wind farm generated noise and adverse health effects: Hearing before the Senate Hearing on 'Excessive Noise from Wind Farms' Bill (14 November 2012).	Exclude	Not research
Thorne B. Wind farm noise and human perception: a review. Enoggera, QLD: Noise Measurement Services Pty Ltd, 2013.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected wind farm emission data
Tickell C. Low frequency, infrasound and amplitude modulation noise from wind turbines - some recent findings. *Acoustics Aust*. 2012;40(1):64-6.	Background Evidence	Presents findings on amplitude modulation
Trustpower Australia Holdings Pty Ltd. Neighbour deed, Palmer Wind Farm, SA. Undated.	Exclude	Not based on new (or new analysis of) systematically collected data
Turnbull C, Turner J, Walsh D. Measurement and level of infrasound from wind farms and other sources. *Acoustics Aust*. 2012;40(1):45.	Background Evidence	Noise survey near wind turbines and other environmental sources
Unit C-KPH. The health impact of wind turbines: A review of the current white, grey, and published literature. Chatham, Ontario, Canada: Chatham-Kent Municipal Council, 2008.	Exclude	Narrative review; not based on new (or new analysis of) systematically collected wind farm emission data
US EPA. Noise pollution. Undated; Available from: http://www.epa.gov/air/noise.html.	Exclude	Information web site: not based on new (or new analysis of) systematically collected data
van den Berg F, Pedersen E, Bouma J, Bakker R. WINDFARM perception: Visual and acoustic impact of wind turbine farms on residents. Final report. Groningen: University of Groningen; Goeteborg University; University Medical Centre, 2008.	Exclude	Already considered and either included or excluded from the Independent Review
Wagner S. Wind turbine noise. Berlin Heidelberg: Springer; 1996.	Exclude	Not based on new (or new analysis of) systematically collected data

CITATIONS OF SUBMITTED LITERATURE	CATEGORY	REASON
Walker B, Hessler G, Hessler D, Rand R, Schomer P. Cooperative measurement survey and analysis of low-frequency and infrasound at the Shirley Wind Farm. Wisconsin Public Service Commission, 2012.	Background Evidence	Systematically collected wind turbine noise data
WHO. Burden of disease from environmental noise. Quantification of healthy life years lost in Europe. Copenhagen: World Health Organization; 2011.	Exclude	Already considered and either included or excluded from the Independent Review
WHO. Night noise guidelines for Europe. Copenhagen: World Health Organization; 2009.	Exclude	Already considered and either included or excluded from the Independent Review
Willingale B. Infrasound and low frequency noise in the locomotive cab. 10th International Congress on Acoustics; Sydney 1980.	Exclude	Extended conference abstract; not based on new (or new analysis of) systematically collected data
Witthoft M, Rubin GJ. Are media warnings about the adverse health effects of modern life self-fulfilling? An experimental study on idiopathic environmental intolerance attributed to electromagnetic fields (IEI-EMF). *J Psychosom Res*. 2013;74(3):206-12.	Parallel Evidence	Small laboratory study not directly about wind farms
Wolsink M. Planning of renewables schemes: Deliberative and fair decision-making on landscape issues instead of reproachful accusations of non-cooperation. *Energy Policy*. 2007;35:2692-704.	Exclude	Not based on new (or new analysis of) systematically collected data
Xue S. UK Amplitude modulation noise analysis and first look at off-shore wind turbine aeroacoustics simulation study. 5th International Conference on Wind Turbine Noise, Denver.	Exclude	Conference abstract
Yano T, Kuwano S, Kageyama T, Sueoka S, Tachibana H. Dose-response relationships for wind turbine noise in Japan. 42nd International Congress and Exposition on Noise Control Engineering; 15-18 September 2013; Innsbruck, Austria.	Direct Evidence	Full conference paper [Secondary publication to Kuwano 2013]
Yokoyama S, Sakamoto S, Tachibana H. Study on the amplitude modulation of wind turbine noise: Part 2 - Auditory experiments. 42nd International Congress and Exposition on Noise Control Engineering; 15-18 September 2013; Innsbruck, Austria.	Exclude	Conference abstract
Zajamsek B, Doolan CJ, Moreau DJ, Hansen K. Simultaneous indoor low-frequency noise, annoyance and direction of arrival monitoring. 5th International Conference on Wind Turbine Noise 28-30 August 2013; Denver.	Background Evidence	Noise levels measured at two households around a wind farm at different distances [Secondary publication to Doolan 2013]
Zajamsek B, Moreau D, Doolan C, Hansen K. Indoor infrasound and low-frequency noise monitoring in a rural environment. Acoustics; 17-20 November 2013; Victor Harbor, SA.	Background Evidence	Preliminary assessment of an annoyance testing tool based on one case [Secondary publication to Doolan 2013]
Zajamsek B, Moreau DJ , Doolan CJ. Characterising noise and annoyance in homes near a wind farm. Acoustics Australia. 2014;42(1):14-9.	Background Evidence	Identified by ONHMRC shortly after the public consultation period [Secondary publications to Doolan 2013]

Appendix 6 – Data extraction forms for included studies

See page 36 for Explanatory Notes

Janssen 2011

Reference [1]

Janssen SA, Vos H, Eisses AR, Pedersen E. A comparison between exposure-response relationships for wind turbine annoyance and annoyance due to other noise sources. *Journal of the Acoustical Society of America*. 2011;130(6):3746-53.

Affiliation/source of funds [2]

Netherlands Organisation for Applied Scientific Research/Funded by the Ministry of Housing, Spatial Planning and the Environment of the Netherlands.

Study design [3]	Level of evidence [4]	Location/setting [5]
Data from 3 previously published cross-sectional surveys; 2 from Sweden and 1 from the Netherlands were combined to investigate exposure-response relationships between noise and annoyance.	IV	One study in an agricultural setting in South Sweden, another in a mixture of urban/rural settings in Sweden and the third in a mixed setting in the Netherlands. **Proximity/distance:** Not specified for the two Swedish studies, within a 2.5 km radius from wind turbines in the Netherlands study.

Exposure description [6]	Control(s) description [8]
Annual day, evening and night A-weighted equivalent noise level (L_{den}) was calculated from the wind turbine noise emission data in the original 3 studies. Assumptions were made about wind velocity of 8 m/sec, a neutral atmosphere and noise at 10 m height, in line with recommendations by European regulatory agencies. **Wind farm details:** Not specified in this paper. **Specific exposure details:** No new exposure data collected for this analysis. **Sample size [7]** 1820 participants in total across the 3 studies (341 + 754 + 725).	No control groups were used in these studies. All comparisons were across the L_{den} exposure gradient for the exposed groups. **Sample size [9]** N/A

Population characteristics [10]

Exposure group:
Mean age 51.5 years, 53.6% female, 48.9% noise sensitive, economic benefit 7.6%, visible wind turbine 74%, rural 45.8% and flat terrain 79.4%. While no formal tests of statistical significance were reported, there are some potentially important differences between the three groups. For example, the Dutch study had a considerably higher percentage of participants with economic benefit from the wind turbines (14.3%), compared with the two Swedish studies (3.0 and 2.7%). Other characteristics where major differences were found include turbine visibility, rural location and flat terrain.

Length of follow-up [11]

N/A as cross-sectional designs used in these studies.

Outcome(s) measured and/or analyses undertaken [12]

Indoor and outdoor annoyance only. No health measures used. Annoyance was measured using a 1-item self-report scale (4-point scale in the Swedish study and a 5-point scale in the Dutch study).

INTERNAL VALIDITY

Confounding subscale [13]

Comment on sources of confounding:
The population characteristics noted above were adjusted for in the models used in the study. However, data on some other potentially important confounders, such as socioeconomic status, medical status, other potential sources of annoyance and country, were either not collected or not adjusted for in the analyses. Therefore, confounding may have affected the results, as annoyance can be influenced by a very wide range of demographic, lifestyle, health and environmental factors.

Bias subscale [14]

Comment on sources of bias:
The major source of bias is participation bias, due to the moderate to low participation rates across the 3 studies. The two Swedish studies had participation rates of 68% and 58%, while participation in the Dutch study was 37%. In the Swedish studies, respondents were not found to differ from the population in the study areas on age and gender (other characteristics not reported) and early vs late respondents were reported not to differ in their answers, but no data on this were reported. In the Dutch study, 200 non-responders were sent a questionnaire about annoyance and 48% responded and no differences in annoyance were found between this group and the study participants. The other likely source of bias is information bias, as all outcome and demographic data were self-reported, including noise sensitivity and annoyance.

EXTERNAL VALIDITY

Generalisability [15]

While appropriate comparator data for communities around wind turbines in Australia are not readily available, the demographic characteristics of the study sample reported in the study are unlikely to be grossly dissimilar from rural communities in Australia. However, socioeconomic and cultural differences between the European countries and Australia are likely to affect generalisability.

Applicability [16]

These analyses were undertaken using data from two European countries (Sweden and the Netherlands). As no data were reported in the study about wind turbine characteristics in the areas where the studies were undertaken, it is not possible to assess whether these finding are applicable to the Australian setting. Applicability to the Australian situation will depend upon the degree of similarity of Australian wind turbines with the wind turbines included in this research. Other possible reasons why applicability may be low is climatic and terrain differences between Australia and the two European countries and sociocultural differences.

Reporting subscale [17]

Comment on quality of reporting:
While not all of the questions in the reporting subscale were applicable to this study, those that were applicable were generally reported satisfactorily. These include aims and objectives, the annoyance outcome which was measured and characteristics of the study population being clearly described. Noise emission levels had been collected in the original studies and development of the exposure metrics (based on these data) for the analyses in this paper were well described. Reporting of the findings was generally satisfactory, although beta coefficients are used with no confidence intervals and just a note of whether they were statistically significant (p< 0.05). Exposure-response relationships were clearly presented in a series of figures.

Chance [18]

As there was only one outcome – annoyance (although this was for annoyance both inside and outside, so two variables) – and only one exposure measure (L_{den}), there was not an excessive number of analyses in the paper, which reduces the potential for chance to explain the associations found.

Overall quality assessment (descriptive) [19]

The design of this pooled study had some strengths over much of the other published epidemiological wind turbine research, such as having a clear and limited set of specific objectives, the large sample size of 1820 participants, acceptable recruitment rates in the two Swedish studies (however, not in the Dutch study), robust exposure metrics based on measured data and high quality reporting in the paper. Conversely, there were some weaknesses, such as the cross-sectional design, using non-validated self-report outcome measures of annoyance and noise sensitivity, pooling data from 3 different studies from 2 different countries (with inevitable differences in methods used, although these are small) and lack of data on potentially important factors which may influence annoyance. Therefore, confidence in the results is considered moderate.

RESULTS

Adverse effect outcomes [20]

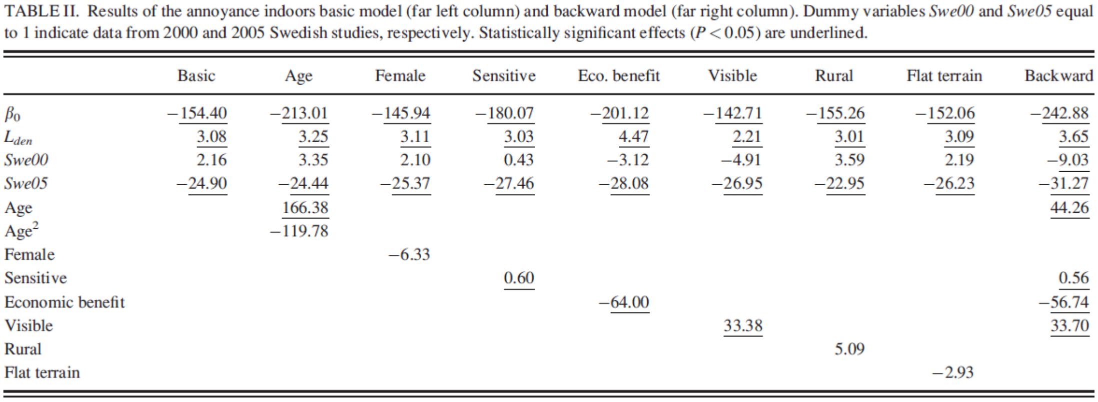

TABLE II. Results of the annoyance indoors basic model (far left column) and backward model (far right column). Dummy variables *Swe00* and *Swe05* equal to 1 indicate data from 2000 and 2005 Swedish studies, respectively. Statistically significant effects ($P < 0.05$) are underlined.

	Basic	Age	Female	Sensitive	Eco. benefit	Visible	Rural	Flat terrain	Backward
β_0	−154.40	−213.01	−145.94	−180.07	−201.12	−142.71	−155.26	−152.06	−242.88
L_{den}	3.08	3.25	3.11	3.03	4.47	2.21	3.01	3.09	3.65
Swe00	2.16	3.35	2.10	0.43	−3.12	−4.91	3.59	2.19	−9.03
Swe05	−24.90	−24.44	−25.37	−27.46	−28.08	−26.95	−22.95	−26.23	−31.27
Age		166.38							44.26
Age^2		−119.78							
Female			−6.33						
Sensitive				0.60					0.56
Economic benefit					−64.00				−56.74
Visible						33.38			33.70
Rural							5.09		
Flat terrain								−2.93	

This table shows that in the adjusted models there was a small positive association between noise level and indoor annoyance. There was significant variability between the three studies, with lower annoyance in the Swedish studies. Visibility of the wind turbines had a considerably stronger positive effect than for the noise level, while self-reported noise sensitivity was only weakly associated with noise. Annoyance was found to be strongly reduced for economic benefit. A similar pattern of associations was found for outdoor annoyance. Repeating the analyses, taking out those who did not benefit economically and not taking the individual study effects into account, resulted in a steeper slope of the relationship between noise and annoyance for both indoors (B = 5.50) and outdoors (B = 5.48).

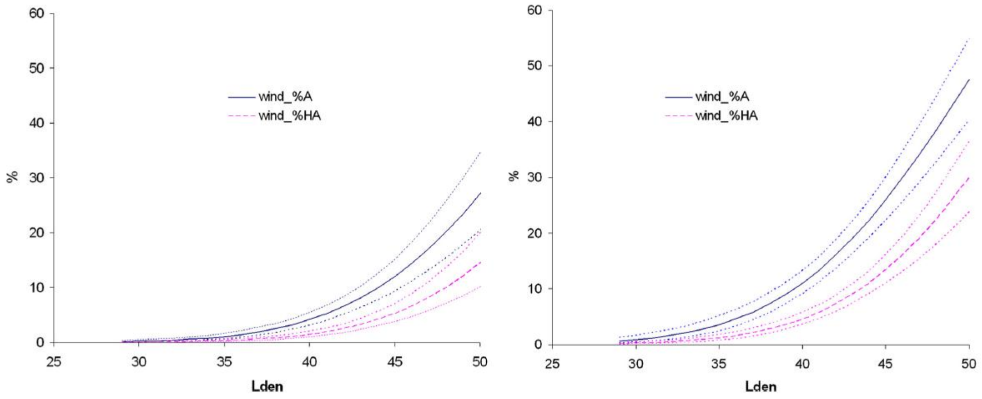

FIG. 1. (Color online) The exposure-response relationships between L_{den} and the percentage of residents annoyed (*%A*) and highly annoyed (*%HA*) indoors (left) and outdoors (right).

This figure demonstrates the shape of the dose-response curve for those defined as annoyed and those highly annoyed. This shows that noise levels up to about 35 dB caused almost no annoyance for both indoors and outdoors. The authors estimated that an L_{den} of 45 dB resulted in 12% annoyed participants indoors and 26% annoyed participants outdoors. It should be noted that the numbers of highly annoyed participants indoors and outdoors were very small (specific numbers not reported) and this, coupled with small numbers exposed above 45 dB, resulted in wide error bars at the higher noise levels.

Exposure group [21]	**Control group [22]**	**Measure of effect / effect size [23]** **95% CI [25]**	**Harms (NNH) [24]** **95% CI [25]**
Indoor annoyance > 50% (the definition of 'annoyed' used in the study) was only 4.2%. Outdoor annoyance > 50% was higher at 8.7%	N/A	Adjusted Beta coefficient for indoor annoyance and L_{den} was 3.65 ($p < 0.05$) Adjusted Beta coefficient for outdoor annoyance and L_{den} was 3.85 ($p < 0.05$)	For both indoors and outdoors, a 1 dB increase in L_{den} was estimated to increase annoyance by about three points on a 100-point scale. No confidence intervals or p-values given.

Public health importance (1–4) [26]	**Relevance (1–5) [27]**
It is difficult to apply the rating scale on page 23 of the NHMRC Guidelines, as it is not suitable for this type of study and it is difficult to consider annoyance in terms of a 'clinically important benefit'. The paper does not address the duration or likely impacts of increased annoyance at higher noise levels from wind turbines. Therefore the public health importance of annoyance from wind turbines, based on the findings from this study, is unclear.	It is difficult to apply the rating scale on page 27 of the NHMRC Guidelines, as it is not suitable for this type of non-intervention study and annoyance has been investigated, rather than 'patient-relevant outcomes'. A more important consideration of relevance is how these findings might apply to the wind turbine situation in Australia, such as proximity of communities, types of wind turbines, measured noise levels and sociocultural differences in what constitutes annoyance compared with Europeans.

Comments [28]

The authors have also attempted to compare annoyance levels related to noise from wind turbines with noise from other environmental sources; aircraft, road and rail. The authors suggested that annoyance is higher from wind turbines compared with the other sources at similar noise levels, but no details are given on the methods used and derivation of the data for the other sources of noise, so such comparisons must be treated with considerable caution. This is the weakest part of this paper.

Kuwano 2013

Reference [1]

Kuwano S, Yano T, Kageyama T, Sueka S, Tachibana H. Social survey on community response to wind turbine noise in Japan. *42nd International Congress and Exposition on Noise Control Engineering*, Innsbruck, Austria, 15-18 September 2013.

Affiliation/source of funds [2]

Osaka University, Japan; Kumamoto University, Japan; Oita University of Nursing and Health Sciences, Japan; Sueoka Professional Engineer Office, Japan; Chiba Institute of Technology, Japan. Funding from the Ministry of the Environment of Japan (Project No. S2-11).

Study design [3]

Cross-sectional survey

Level of evidence [4]

IV

Location/setting [5]

Japan

Proximity/distance:

Not reported in present paper (see Yano 2013)

Exposure description [6]

Wind farm details:

36 ‘target sites’ were identified with audible wind turbine noise from Hokkaido to Okinawa, Japan. Details of wind farm installations not provided (see Yano 2013).

Specific exposure details:

Not reported in present paper (see Yano 2013: Average sound pressure 26-50 dB).

Sample size [7]

747 respondents in ‘target site’ areas were approached by door knocking, of whom 49% participated (n=~ 366, calculated).

Control(s) description [8]

Residents at 16 control sites where wind turbine noise is inaudible and no turbines were visible.

Sample size [9]

332 control site respondents were approached by door knocking, of whom 45% responded (n= ~145, calculated).

Population characteristics [10]

Exposure group

Approximately equal sex ratio, with approximately 80% over 50 years of age (and approximately 30% over 70). Statistical tests for differences between exposed and control group demographics not mentioned.

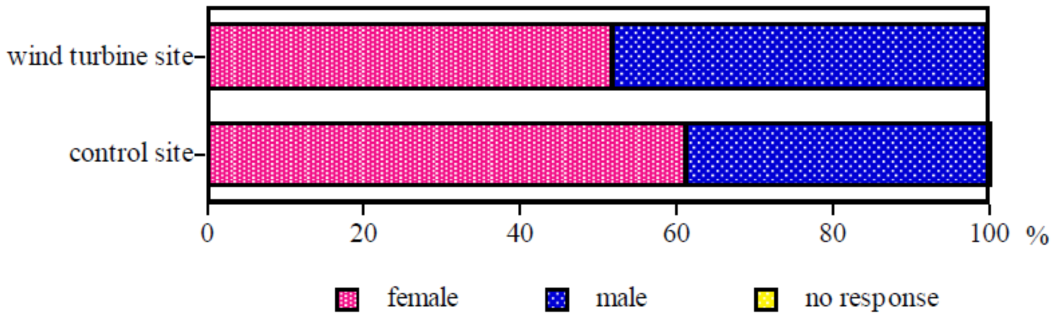

Figure1 Sex of the respondents

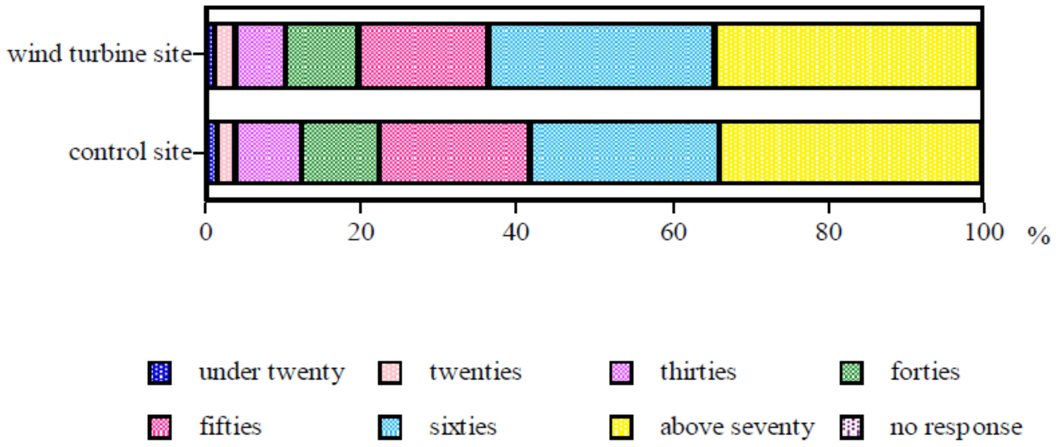

Figure 2 Age of the respondents

Length of follow-up [11]	**Outcome(s) measured and/or analyses undertaken [12]**
N/A as cross-sectional study design used.	Self-reported satisfaction with living environment (shopping convenience, transportation, amount of greenery, clean air, quietness and public facilities). Self-reported degree of annoyance of road traffic noise, aircraft noise, high-speed train (Shinkansen) noise, conventional train noise, noise from factories, construction noise and wind turbine noise (5 step categories). Self-reported trouble with sleep.

INTERNAL VALIDITY

Confounding subscale [13]

Comment on sources of confounding:
No confounders are identified by the authors, however few demographic variables are reported and differences not tested statistically.

Bias subscale [14]

Comment on sources of bias:
Poor response rate indicates potential for selection bias. Blinding is not mentioned but very general nature of survey questions appears to indicate that respondents may have been blinded to purpose, possibly reducing potential for selection bias.

EXTERNAL VALIDITY

Generalisability [15]

Cross-sectional survey limits ability to determine causality. Elderly residents over-represented in sample, limits generalisability to younger age groups and broader population. Likely that Japanese expectations of local amenity are dissimilar to Australian expectations.

Applicability [16]

Population density in wind turbine areas surveyed not clear but likely more dense than wind turbine areas in Australia which are typically rural and relatively sparsely populated. Likely differences in background noise and sound paths due to different environments.

Reporting subscale [17]

Comment on quality of reporting:
Key details unreported, for example full description of the wind turbine and control areas (urban/rural, population density), numerical results not provided (predominantly histograms only), tests of statistical significance and detailed recruitment methodology.

Chance [18]

N/a, no statistical tests for differences.

Overall quality assessment (descriptive) [19]

There is potential for misclassification of exposure (duration of exposure not quantified), sample selection bias (low response rate) and confounding. Survey design does not permit authors to definitively link outcomes to wind turbine noise exposure.

RESULTS

Adverse effect outcomes [20]

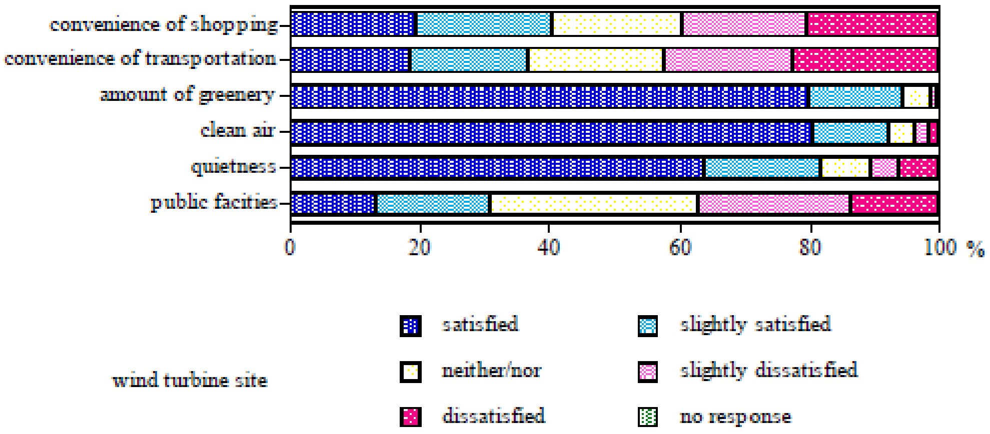

Figure 3 Satisfaction with their living environment in wind turbine site

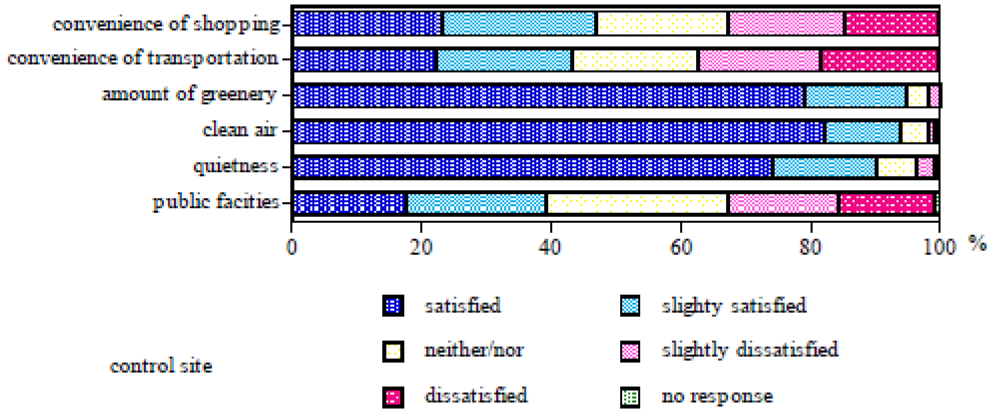

Figure 4 Satisfaction with their living environment in control site

Statistical tests not reported by satisfaction with living environment metrics, however the authors highlight a difference between satisfaction with quietness between wind turbine sites and control sites.

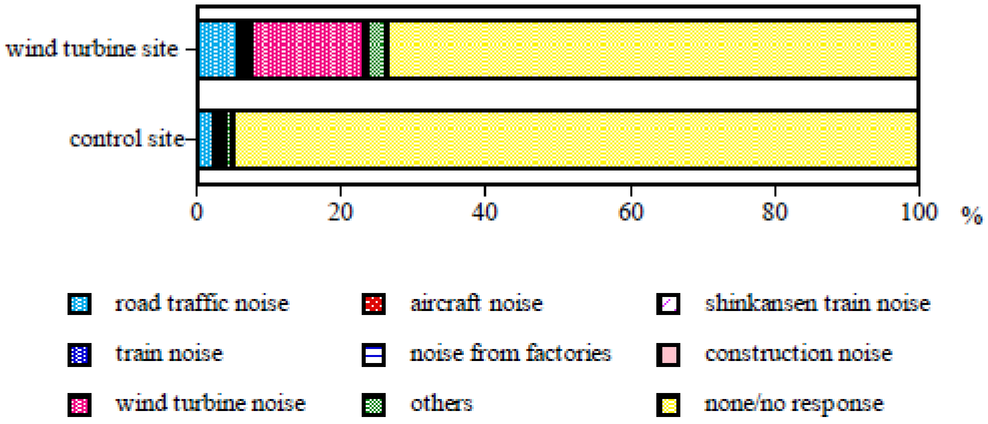

Figure 5 Most annoying sound

Statistical tests not reported, but more control site respondents reported no concerns with noise compared with wind turbine site respondents and more wind turbine site respondents reported that wind turbines were the most annoying sound in their environment. However, more wind turbine respondents also nominated road traffic noise or "other" noise as their most annoying noise suggesting that wind turbine areas surveyed may have a different overall noise profile compared with control areas.

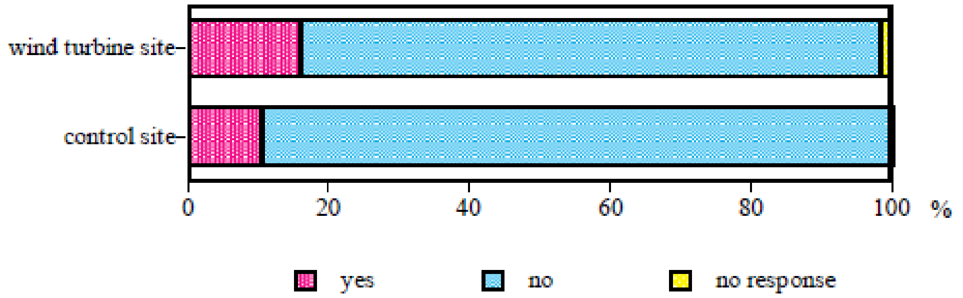

Figure 6 The percentage of the responses to the question whether they had a trouble with sleep.

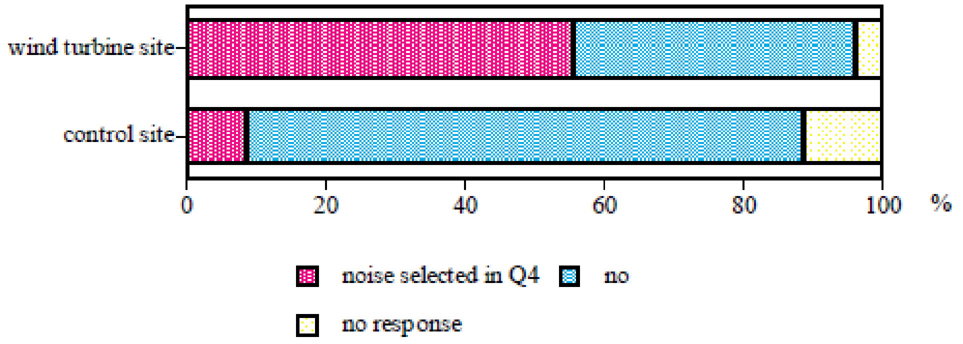

Figure 7 The reason of the trouble with sleep.

Statistical tests not reported but somewhat more wind turbine site respondents reported trouble with sleep. More wind turbine site respondents also did not answer this question. Wind turbine site respondents who had trouble sleeping were reportedly more likely to identify noise as the reason. However, what type of noise was apparently not investigated and earlier questions indicated that this group were troubled more than control groups by other types of noise as well as wind turbine noise.

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].	No effect measures presented and no 95% CIs	N/A

Public health importance (1–4) [26]	**Relevance (1–5) [27]**
It is difficult to apply the rating scale on page 23 of the NHMRC Guidelines, as it is not suitable for this type of study, where many outcomes have been measured, but given the limitations of this research, the lowest ranking (4) seems most appropriate.	It is difficult to apply the rating scale on page 27 of the NHMRC Guidelines, as it is not suitable for this type of non-intervention study, but given the limitations of this research, the lowest ranking (5) seems most appropriate.

Comments [28]
This cross-sectional survey does not permit any conclusions about causation and it is unclear whether the reported differences between control and exposed groups are associated with wind turbine noise. Survey design does not associate reported outcomes to wind turbine noise and the overall noise profile of control areas and wind turbine areas may be systematically different in other ways. Lack of statistical testing makes it difficult to determine if differences between control and exposed groups are likely to be due to chance. Low recruitment rate indicates possibility for recruitment bias and over-recruitment of elderly residents limits generalisability to broader population. Context poorly described but likely to be very different to the Australian context of wind turbine exposure, limiting generalisability to the Australian context. This study has very limited capacity to inform the assessment of wind turbine noise of adverse health effects.

Abbreviations: NR = not reported; NC = not calculable; N/A = not applicable

McBride 2013

Reference [1]		
McBride D, Shepherd D, Welch D, Dirks K. A longitudinal study of the impact of wind turbine proximity on health related quality of life. *42nd International Congress and Exposition on Noise Control Engineering*, Innsbruck, Austria, 15-18 September 2013		
Affiliation/source of funds [2] Department of preventive and Social Medicine, University of Otago, NZ Department of Psychology, School of public Health, Auckland University of Technology, NZ School of Population Health, The University of Auckland, NZ Funding source not given.		
Study design [3]	**Level of evidence [4]**	**Location/setting [5]**
Repeated cross-sectional study (using the same design as an earlier study conducted in this community in 2010, but a different sample of the population).	IV	Makara Valley, New Zealand; hilly terrain with long ridges 250-450 m above sea level. **Proximity/distance:** Exposed participants in dwellings <2 km from nearest wind turbine; non-exposed controls resided (n = 250 homes) >10 km from turbine installation.

Exposure description [6]

Wind farm details:

66 turbines (Siemens SWT-2.3-82 VS)

Turbine height =125 m

Rotor diameter =82 m

Specific exposure details:

Measured $L_{95(10mins)}$ Typical noise exposure range 20 dB(A) to 54 dB(A)

Sample size [7]

Not stated. Present sample not same as 2010 survey.

Control(s) description [8]

Selected from 250 homes located in a socioeconomically and geographically matched area differing from the exposure group only by distance from wind turbines (≥ 10 km).

Sample size [9]

Not stated. Present sample not same as 2010 survey (Shepherd, 2011).

Shepherd 2011
Shepherd D, et al. Evaluating the impact of wind turbine noise on health-related quality of life. *Noise & Health* 2011;**13**(54):333-9, doi: 10.4103/1463-1741.85502.

Population characteristics [10]

Exposure group:
The exposure group recruited from population of residents of 56 dwellings in the Makara Valley which were within a 2 km radius of a single wind turbine. Recruitment rate and actual number of respondents included in analysis were not stated. Noise measurements indicated sound levels between 20 dB(A) and 54 dB(A). Amplitude modulation effects were identified by independent investigation.

Length of follow-up [11]

n/a, cross-sectional study. A 2-year follow-up of a previous cross-sectional survey of the same community (different sample).

Outcome(s) measured and/or analyses undertaken [12]

The WHOQOL-BREF (26 item version) measured physical (7 items), psychological (6 items), and social (3 items) HRQOL, an additional eight item domain measuring environmental QOL and 2 'generic' items asking about general health and overall quality of life. Two amenity items were included.

INTERNAL VALIDITY

Confounding subscale [13]

Comment on sources of confounding:
Detail about recruitment, selection and matching not provided in present report, however the methodology was presumably common to the 2010 survey and a number of limitations were evident in Shepherd 2011 which indicated possible confounding. For example, unequal distribution of some baseline characteristics between groups, not statistically significant. Socioeconomic and geographic matching was undertaken and adjustment by length of residence. Unclear whether there was any clustering effect of responses as two questionnaires delivered to each household or if clustering was accounted for in analysis. Plausible confounders not addressed, i.e. age, education, chronic disease and risk factors for chronic disease, occupation, employment, background noise, and turbine visibility (see Shepherd 2011).

EXTERNAL VALIDITY

Generalisability [15]

Survey sample members were either within 2 km of a turbine (exposed) at least 10km from a turbine installation (non-exposed); potential for demographic differences between the exposed and control populations. Difficult to assess on basis of limited information provided about recruitment process and recruitment rates.

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.

Authors note that "NZ wind farms are often situated in complex terrain" typical NZ terrain is generally dissimilar to terrain in most parts of Australia.

Participants were blinded to study purpose in original survey but authors acknowledge participants possibly unblinded in present survey due to publicity associated with original survey. **Bias subscale [14]** ***Comment on sources of bias:*** Response bias may be present. Insufficient detail about recruitment process and recruitment rate to evaluate. Response rates in 2010 survey were poor (see Shepherd, 2011). Response bias self-selection may have been more likely in 2012 survey than in 2010 survey because blinding to purpose of the study likely less effective. Authors report that five comparison group respondents were excluded because they were multivariate outliers (as defined by extreme Mahalanobis distances), with response set acquiescence clearly evident in all five cases. Without knowing the actual number of control participants it is unclear how large a proportion of the control group these five represent.	
Reporting subscale [17] ***Comment on quality of reporting:*** Certain key details not reported, for example the recruitment rate and total number of exposed and comparison group participants.	
Chance [18] No mention of statistical adjustments for chance.	
Overall quality assessment (descriptive) [19] High probability of exposure misclassification (exposure time not well-defined), sample selection bias (if response rate similar to 2010 survey, approximately 34%), and confounding. There is also the potential for outcome misclassification (amenity questions apparently not validated instruments) and recall bias (unclear if blinding to study purpose was effective, likely to have been less effective than in 2010). Potential lack of blinding to study purpose would plausibly increase selection bias, favouring recruitment of concerned individuals. In the context of this review, this study is considered poor quality.	

RESULTS

Adverse effect outcomes [20]

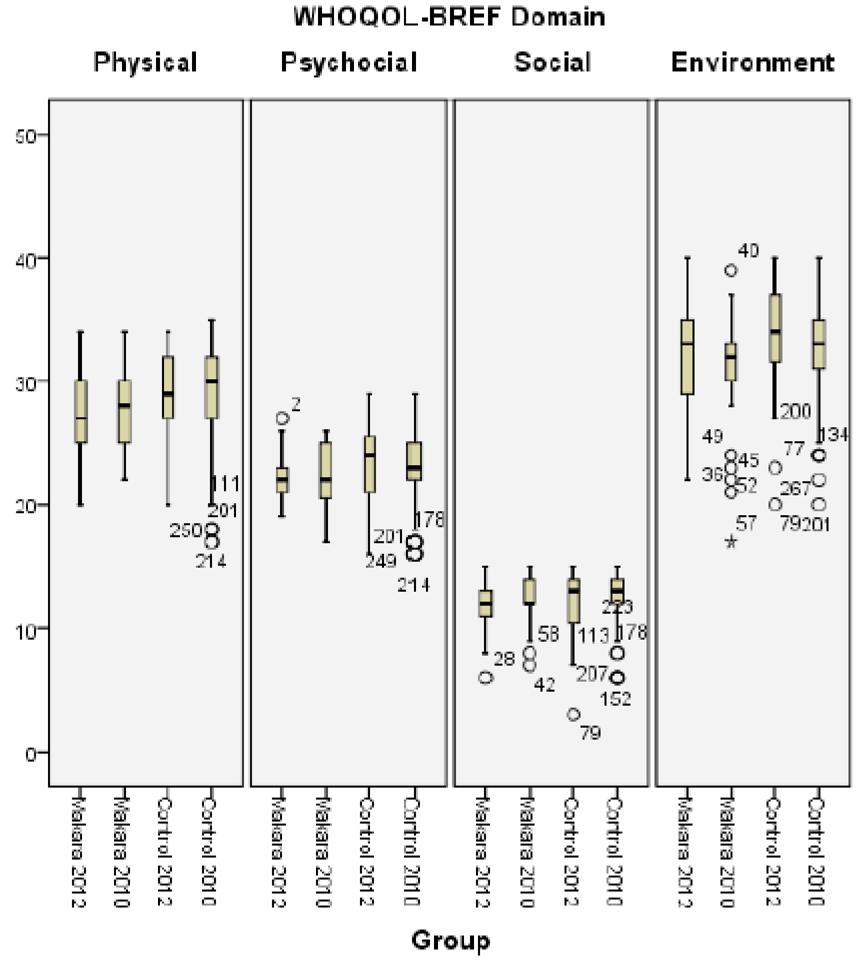

Figure 1, box-plot of WHOQOL-BREF domain scores for turbine and control groups.

There was little difference evident in WHOQOL scores among exposed (Makara) residents in 2010 and 2012. In the current survey, exposed residents scored significantly lower (i.e. poorer) than (2012) control residents in the physical domain (Mann-Whitney U test p=0.043). Examination of individual WHOQOL questions revealed that exposed residents scored significantly lower (i.e. poorer) on the question, “how satisfied are you with your health.” (p = 0.020).

The Amenity scores are shown in figure 2.

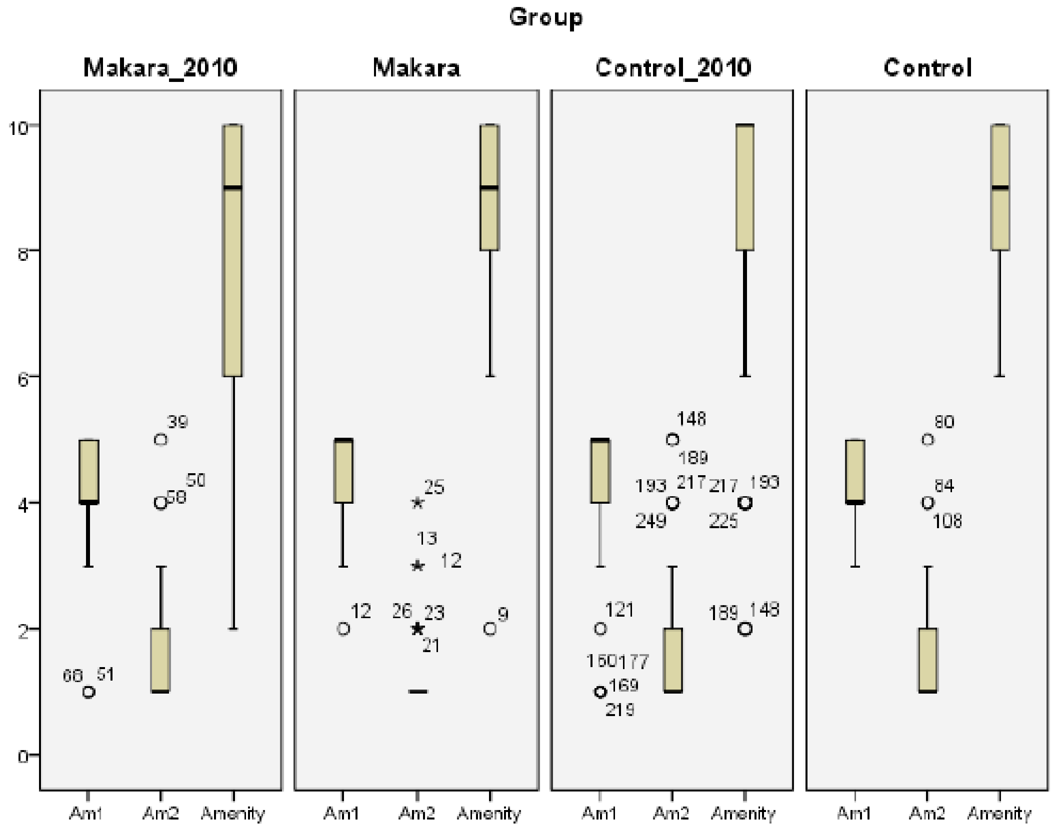

Figure 2, box-plot of amenity scores for turbine and control groups.

Answers to the amenity questions indicated no significant difference in scores over time, however there was a significant decrease in amenity in the control group over time (p = 0.034)

Exposure group [21]	**Control group [22]**	**Measure of effect / effect size [23]**	**Harms (NNH) [24]**
See 'Adverse effect outcomes' [20].	See 'Adverse effect outcomes' [20].	**95% CI [25]** See 'Adverse effect outcomes' [20].	**95% CI [25]** Health effects not reported.

Public health importance (1–4) [26]	**Relevance (1–5) [27]**
It is difficult to apply the rating scale on page 23 of the NHMRC Guidelines, as it is not suitable for this type of study, where many outcomes have been measured, but given the limitations of this research, the lowest ranking (4) seems most appropriate.	It is difficult to apply the rating scale on page 27 of the NHMRC Guidelines, as it is not suitable for this type of non-intervention study, but given the limitations of this research, the lowest ranking (5) seems most appropriate.

Comments [28]
This cross-sectional study, although it replicates a previous cross-sectional study in the same community, does not permit conclusions regarding causality. Therefore, it is unknown if the exposure preceded the self-reported health and amenity outcomes. Also, given that the outcomes are based on self-report, it is plausible that pre-existing opinions about the turbine installation in question and/or about wind turbines in general may have influenced participant recruitment and/or self-reported outcomes. Differences between groups were small and potentially influenced by factors other than exposure to the turbine, given that other confounders were not taken into account in the analysis. Follow up of individuals in comparison to communities would have been more beneficial. This 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; N/A = not applicable

Mroczek 2012

Reference [1]
Mroczek B, Kurpas D, Karakiewicz B. Influence of distances between places of residence and wind farms on the quality of life in nearby areas. *Annals of Agricultural and Environmental Medicine*. 2012;19(4):692-6.

Affiliation/source of funds [2]
Public Health Department, Pommeranian Medical University, Szczecin, Poland Family Medicine Department, medical University, Wroclaw, Poland Public Higher medical Professional School, Opole, Poland

Study design [3]	**Level of evidence [4]**	**Location/setting [5]**
Cross-sectional survey	IV	Northern Poland, the Mazurian, Greater Poland and Lower Silesian Province, Podlaskie Province and Sub-Carpathian Province **Proximity/distance:** People living less than 700 m, 700-1000 m and greater than 1500 m from wind farms

Exposure description [6]	**Control(s) description [8]**
Wind farm details: No details of wind farms provided except that there were 34 wind farms in Northern Poland; the Mazurian, Greater Poland and Lower Silesian Province had 12 wind farms; Podlaskie Province had 11 and Sub-Carpathian Province had 9 wind farms. **Specific exposure details:** **Sample size [7]** 1277 respondents (703 women and 574 men)	No non-exposed groups were included in the study. **Sample size [9]** N/A

Population characteristics [10]

Exposure group: The mean age was 45.54±16.1 years (18-94).

Five exposure groups were described by the distance from the responders house to a wind farm:

Distance 1: below 700 m; Distance 2: 700 m - 1000 m; Distance 3: 1000 m - 1500 m; Distance 4: more than 1500 m; Distance 5: knows nothing about the plans of wind farm construction.

Length of follow-up [11] N/A

Outcome(s) measured and/or analyses undertaken [12] The respondents assessed their health through answering questions in SF-36 and VAS. SF-36 divided up into 8 sub-scales:

- Physical functioning (PF)
- Role-functioning physical (RP)
- Bodily pain (BP)
- General health (GH)
- Vitality (V)
- Social functioning (SF)
- Role functioning emotional (RE)
- Mental health (HE)

INTERNAL VALIDITY

Confounding subscale [13]

Comment on sources of confounding:
Plausible confounders that were not addressed included SES factors, chronic diseases and risk factors for chronic diseases and occupation.

Bias subscale [14]

Comment on sources of bias:
Unknown whether respondents influenced by renting their land for wind farm construction and use. Response rate not given and distance was used as a crude surrogate for noise and visual exposure of wind turbines.

EXTERNAL VALIDITY

Generalisability [15]

Subjects were randomly chosen using a two stage sampling technique. Results may be generalisable to responders only.

Applicability [16]

Unknown whether the population characteristics and wind turbine exposure of those living around wind turbines in Poland are comparable to those living near wind farms in Australia.

Reporting subscale [17]

Comment on quality of reporting:

Overall good reporting of results but lack of data on non-responders, participant characteristics such as chronic disease status and SES.

Chance [18] Chance findings due to multiple statistical testing cannot be excluded.

Overall quality assessment (descriptive) [19] Overall the use of the SF-36 and VAS as tools for Quality of Life (QoL) was well described. However, exposure assessment was crudely described by distance groups, no information was given regarding non-responders, subjects were not blinded and whether responders were renting land to the wind farm operators.

RESULTS

Adverse effect outcomes [20]

It was found that the distance between a place of residence and a wind farm had an effect on the QoL, where the closer the house to a wind farm the higher the QoL. The detailed results are as follows:

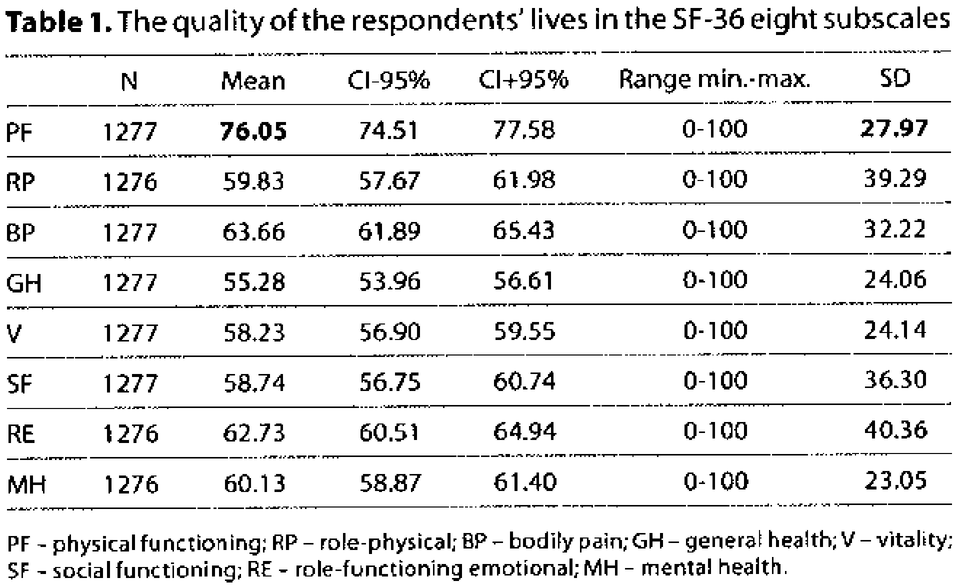

Table 1. The quality of the respondents' lives in the SF-36 eight subscales

	N	Mean	CI-95%	CI+95%	Range min.-max.	SD
PF	1277	**76.05**	74.51	77.58	0-100	**27.97**
RP	1276	59.83	57.67	61.98	0-100	39.29
BP	1277	63.66	61.89	65.43	0-100	32.22
GH	1277	55.28	53.96	56.61	0-100	24.06
V	1277	58.23	56.90	59.55	0-100	24.14
SF	1277	58.74	56.75	60.74	0-100	36.30
RE	1276	62.73	60.51	64.94	0-100	40.36
MH	1276	60.13	58.87	61.40	0-100	23.05

PF – physical functioning; RP – role-physical; BP – bodily pain; GH – general health; V – vitality; SF – social functioning; RE – role-functioning emotional; MH – mental health.

Of the eight aspects of QoL evaluated in the survey (Table 1), results indicated that respondents rated their physical functioning (PF subscale) higher than other aspects of QoL and they rated their general health (GH subscale) lower than other aspects of QoL.

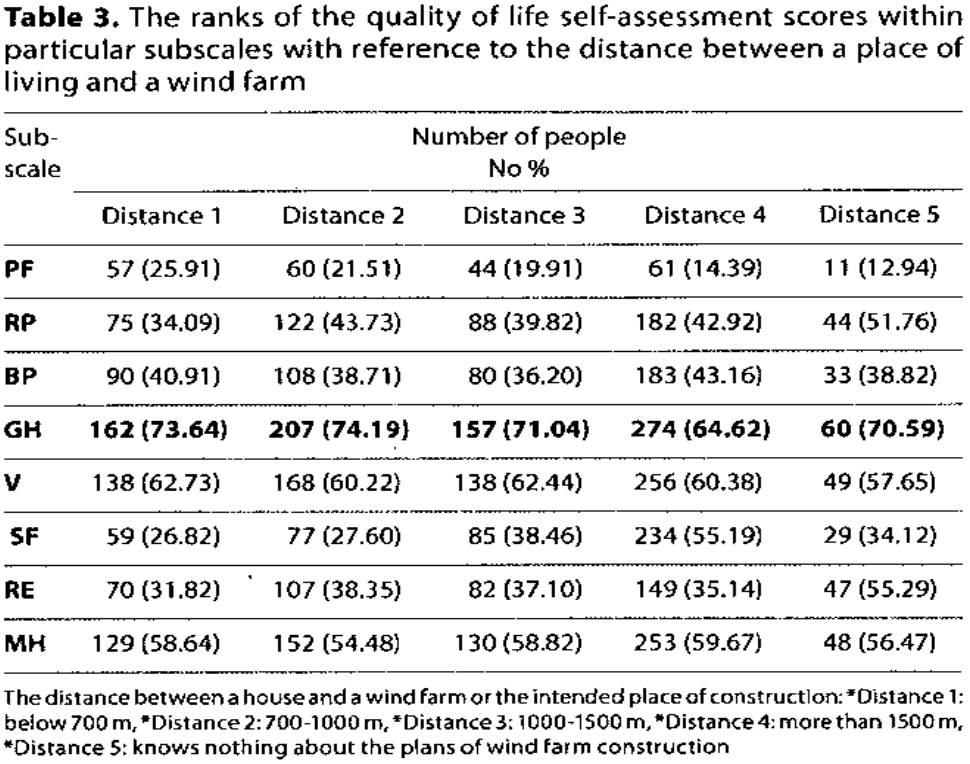

Table 3. The ranks of the quality of life self-assessment scores within particular subscales with reference to the distance between a place of living and a wind farm

Sub-scale	Number of people No %				
	Distance 1	Distance 2	Distance 3	Distance 4	Distance 5
PF	57 (25.91)	60 (21.51)	44 (19.91)	61 (14.39)	11 (12.94)
RP	75 (34.09)	122 (43.73)	88 (39.82)	182 (42.92)	44 (51.76)
BP	90 (40.91)	108 (38.71)	80 (36.20)	183 (43.16)	33 (38.82)
GH	**162 (73.64)**	**207 (74.19)**	**157 (71.04)**	**274 (64.62)**	**60 (70.59)**
V	138 (62.73)	168 (60.22)	138 (62.44)	256 (60.38)	49 (57.65)
SF	59 (26.82)	77 (27.60)	85 (38.46)	234 (55.19)	29 (34.12)
RE	70 (31.82)	107 (38.35)	82 (37.10)	149 (35.14)	47 (55.29)
MH	129 (58.64)	152 (54.48)	130 (58.82)	253 (59.67)	48 (56.47)

The distance between a house and a wind farm or the intended place of construction: *Distance 1: below 700 m, *Distance 2: 700-1000 m, *Distance 3: 1000-1500 m, *Distance 4: more than 1500 m, *Distance 5: knows nothing about the plans of wind farm construction

Table 3 reports the proportion of respondents within each distance category who scored less than or equal to 4 on each QoL subscale. Low QoL scores (</=4) were most common on the general health (GH) subscale

and did not appear to be influenced by distance and was similar for men and women.

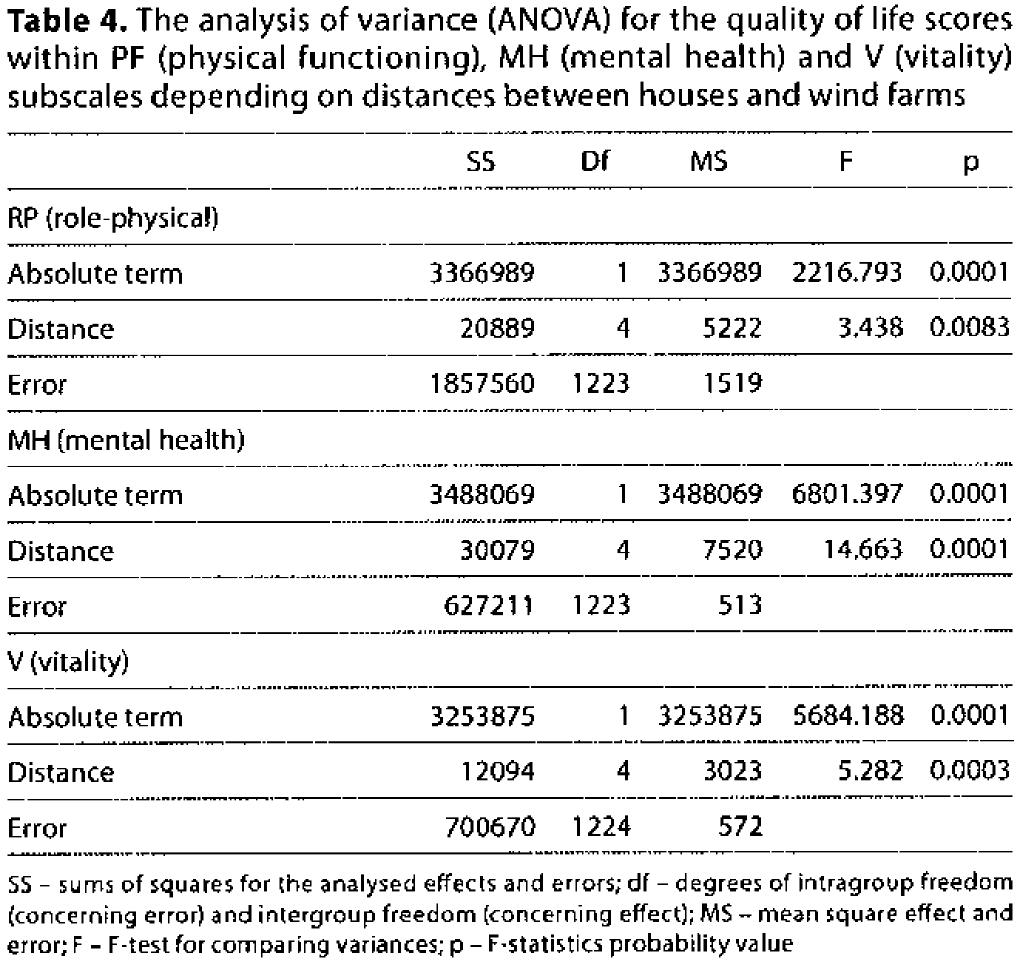

Table 4. The analysis of variance (ANOVA) for the quality of life scores within PF (physical functioning), MH (mental health) and V (vitality) subscales depending on distances between houses and wind farms

	SS	Df	MS	F	p
RP (role-physical)					
Absolute term	3366989	1	3366989	2216.793	0.0001
Distance	20889	4	5222	3.438	0.0083
Error	1857560	1223	1519		
MH (mental health)					
Absolute term	3488069	1	3488069	6801.397	0.0001
Distance	30079	4	7520	14.663	0.0001
Error	627211	1223	513		
V (vitality)					
Absolute term	3253875	1	3253875	5684.188	0.0001
Distance	12094	4	3023	5.282	0.0003
Error	700670	1224	572		

SS – sums of squares for the analysed effects and errors; df – degrees of intragroup freedom (concerning error) and intergroup freedom (concerning effect); MS – mean square effect and error; F – F-test for comparing variances; p – F-statistics probability value

Each quality of life area was evaluated separately using analysis of variance (ANOVA) (results for role-physical, mental health and vitality were reported, see Table 4) and the authors reported that distance to wind farm was a statistically significant predictor of self-reported QoL scores within the role-physical (RP), mental health (MH) and vitality (V) subscales ($p < 0.05$).

Post-hoc analysis using a Tukey test for unequal group sizes found no significant differences between groups in the QoL scores within the role-physical (RP), mental health (MH) and vitality (V) subscales between distance groups. The Tukey test found that people living more than 1,500 m from a wind farm assessed their vitality (V) significantly lower than those living in the closest distance from a wind farm ($p < 0.05$) and respondents living in the closest distance from a wind farm assessed mental health QoL (MH) significantly higher than to those living from 1,000 m - 1,500 m or more from a wind farm ($p < 0.05$ in both cases).

Distance to wind farm was associated with reported social functioning (SF) QoL and the role functioning-emotional (RE) QoL ($p<0.05$). Multiple comparison test showed that people living within the distance of 1,000 m - 1,500m or more from a wind farm assessed their social functioning (SF) QoL significantly lower than those living closer, and those who did not know about the plans for construction of a wind farm (all $p < 0.05$).

Statistically significant differences in the QoL scores within other subscales were not found between other groups of respondents with reference to the distance between a place of residence and a wind farm.

Regression analysis was also performed to estimate the parameters of a model describing the QoL perception with reference to socio-demographic and health variables (including whether respondents worked, learned or had a farm) within the particular subscales, however those variables that were

<table>
<tr><td colspan="4">statistically significant had only limited influence on how respondents perceived their QoL.
Overall, those living in the immediate neighbourhood of wind farms assessed their QoL higher than those living further away and the authors acknowledge that confounders (such as personal gain from nearby wind farm development) which were not assessed in this research project may have influenced the results.</td></tr>
<tr><td>Exposure group [21]
See ‘Adverse effect outcomes’ [20]</td><td>Control group [22]
See ‘Adverse effect outcomes’ [20]</td><td>Measure of effect / effect size [23]
95% CI [25]
See ‘Adverse effect outcomes’ [20]</td><td>Harms (NNH) [24]
95% CI [25]
See ‘Adverse effect outcomes’ [20]</td></tr>
<tr><td colspan="2">Public health importance (1–4) [26]
It is difficult to apply the rating scale on page 23 of the NHMRC Guidelines, as it is not suitable for this type of study, but given the limitations of this research, the lowest ranking (4) seems most appropriate.</td><td colspan="2">Relevance (1–5) [27]
4: evidence of an effect on proven surrogate outcomes but for a different intervention and population.</td></tr>
<tr><td colspan="4">Comments [28] This study was cross-sectional in design and does not permit any conclusions regarding causation between QoL and wind farms. The finding that QoL was inversely related to distance of home from a wind farm was unconvincing given the lack of data regarding responders living near wind farms receiving rent from wind farm operators. Other bias and confounders were not addressed and this study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.</td></tr>
</table>

Abbreviations: NR = not reported; NC = not calculable; N/A = not applicable

Paller 2014

Reference [1]

Paller, C. Exploring the association between proximity to industrial wind turbines and self-reported health outcomes in Ontario, Canada. Master of Science Thesis; 2014.

Affiliation/source of funds [2]

University of Waterloo, Ontario, Canada

Funded by Ontario Research Chair in Renewable Energy Technologies and Health

Study design [3]

Cross-sectional study undertaken between February and May 2013.

Level of evidence [4]

IV

Location/setting [5]

Wind farms in Ontario, Canada

Proximity/distance:

The mean self-reported distances of survey respondents to wind farms was 2.78 km ±3.95 km (range 0.4 m - 55,000 metres). The mean calculated distance from residence to the closest industrial wind turbine was 4.52 km ±4.42 km (range 316 m - 22,661 m), therefore participants underestimated by about 1.6 km their distance from the wind farms.

Exposure description [6]

Wind farm details:

The largest wind farm in each of eight counties in Ontario. Number of turbines ranging from 18-110 turbines per farm and turbine installed capacity ranging from 1.5 MW to 2.3 MW.

Specific exposure details:

Exposure was assessed by calculated distance to nearest turbine from each respondent's home, using geocoding (ArcGIS). Distances were ranked by percentile (1st percentile – 100th percentile) and then divided into 4: quartile 1<25th percentile, quartile 2 <50th, quartile 3 <75th and quartile 4 <100th percentile. From these quartiles, four setback groups were created. In addition, self-reported distances to nearest wind turbine were compared to calculated distances using ArcGIS.

Sample size [7]

The survey questionnaire was sent to 4,876 residences (i.e. sum of houses, apartments and farms), including one reminder, with 412 returned (8.45% response rate) of which only 396 (8.12%) were included in the analysis because 16 did not include an address. Only those residences which did not opt out of receiving unaddressed mail could be approached; 86.8% of the total eligible population. Response rates varied by county between 6.9% and 12.4%.

Control(s) description [8]

No non-exposed groups were included in this study. The reference group for the analyses was the group in the quartile furthest away from the wind farms, based on calculated distance.

Sample size [9]

N/A

Population characteristics [10]

Exposure group:

The questionnaire collected the following possible confounding factors; age, gender, county, marital status, income and education level, but only some were used for adjustment in some analyses.

Length of follow-up [11]	Outcome(s) measured and/or analyses undertaken [12]
N/A	Pittsburgh Sleep Quality Index (PSIQ) SF-12 The Satisfaction with Life Scale (SWLS) Wind Turbine Syndrome (WTS) Index using 8 questions drawn from the Quality of Life and Renewable Energy Technologies Study survey. Frequency of the following symptoms in the past month: headache, irritability, concentration problems, nausea, vertigo, undue tiredness, tinnitus.

INTERNAL VALIDITY

Confounding subscale [13]

Comment on sources of confounding:
Age, gender and county were used for adjustment in some analyses, but not the other collected demographic information (education, income, marital status) and no other potential lifestyle, health or environmental confounders.

Confounding is likely to have affected the results, as many of the outcomes used, such as quality of life, symptomatology, sleep and life satisfaction are influenced by a very wide range of demographic, lifestyle, health and environmental factors.

Bias subscale [14]

Comment on sources of bias:
The major source of bias is participation bias, due to the very low participation rate, which averaged 8.45% across the eight counties. While there was an attempt to assess degree of likely response bias in two ways, neither method was very convincing, as neither comparison involved the non-responders. The first method involved comparing the responders with the whole population in the county and large differences were found on many demographic characteristics, but the approached population would not be representative of the whole County population, so this isn't very meaningful. The other method of trying to assess participation bias was to compare the participants from the two counties with the highest (12.4%) and lowest (6.9%) participation rates. Many of the factors were similar, but some large differences were found (e.g. tinnitus prevalence, SF-12 and WTS prevalence, often in different directions), it is difficult to interpret this in relation to the impact of any response bias, as both counties had very low participation rates. If one county had a very high participation rate, these results would have been more meaningful. The other likely source of bias is information bias, as the self-reported distance from the nearest wind farm was grossly underestimated. No blinding was possible.

EXTERNAL VALIDITY

Generalisability [15]

The study sample had a median age of 56 years, 52% male, 79% married, median income of $60,000 and 59% having undertaken post-secondary education. No other demographic or other characteristics for the study sample were reported. While appropriate comparator data for communities around wind farms in Australia are not readily available, the demographic characteristics of the study sample are unlikely to be grossly dissimilar from rural communities in Australia. A more important point which is likely to affect generalisability is the low participation rate of the study sample and the high likelihood that it is unrepresentative of the community around wind farms.

Applicability [16]

The study was undertaken in Canada and the researcher chose the largest wind farms in each county around which to undertake this study. These farms contained a wide variety of wind turbines (Table 2), with varying size, manufacturer and number of turbines in the wind farm ranging from 18 to 110. Applicability to the Australian situation will depend upon the degree of similarity of Australian wind farms with the wind farms included in this research. Other possible reasons why applicability may be low is differences in local terrain around the wind farms between Australia and Canada and proximity of surrounding residences.

Reporting subscale [17]

Comment on quality of reporting:

While not all of the questions in the reporting scale were applicable to this study, those that were applicable were generally reported satisfactorily. These include aims/objectives, main outcomes which were measured and characteristics of the study population being clearly described. Other aspects of the study, such as exposure (calculated distance only) and principal confounders were less well described or ignored. Reporting of the findings and random variability were very poorly described, with an absence of measures of risk or 95% confidence intervals, the overuse of p-values and the reporting of regression analyses, without the presentation of the descriptive data on which the regressions were based. Distance-response relationships, while shown in figures for some outcomes, were also not adequately investigated or reported.

Chance [18]

There were many analyses conducted, including analyses comparing across the individual wind farms (e.g. Table 13), although not all of the analyses which were undertaken were reported in this thesis. The findings for outcomes where associations were found, such as for PSQI, vertigo and tinnitus, were reported in the Tables, but the findings related to outcomes for which no associations were found were generally not reported in Tables. In addition, when a summary measure was analysed and no association with distance was found, variables which made up the summary measure were then analysed, for example the WTS index was found not to be related to distance, so the 8 variables which make up that index were analysed individually, so increasing the number of analyses. Therefore, taking into account all of these factors, it was difficult to determine the total number of analyses, but this is likely to have been very high given the number of wind farms, the number of outcome measures and their component variables. No correction for multiple comparisons was undertaken. Therefore, chance cannot be excluded as an explanation for at least some of the associations found.

Overall quality assessment (descriptive) [19]

While the design of this study had some strengths over much previous epidemiological research related to the study of wind farms and health outcomes (e.g. including several wind farms, trying to recruit a large population, using some validated instruments (e.g. the SF-12), some other parts of the study design and some aspects of the execution were poor on several levels. These included the very low participation rates across the different counties, the lack of any exposure data apart from calculated distance, the use of some non-validated instruments (e.g. symptom reporting and the WTS index), lack of data on potentially important confounders, multiple comparisons and selective reporting of results. Therefore, confidence in the results is considered low.

RESULTS

Adverse effect outcomes [20]

The main reported outcomes are:

Association between the logarithm of distance and PSQI, with sleep improving with greater distance from the wind farm (adjusted R-Squared value of 0.08 and p-value of 0.01 for the adjusted model were the only ways that these findings were presented).

Association between logarithm of distance and vertigo, with vertigo worse among participants living closer to the wind farm (adjusted R-Squared value of 0.11 and p-value of < 0.001 for the adjusted model were the only ways that these findings were presented).

Distance-response relationships were presented for those outcomes shown to be associated with the logarithm distance (PSQI and vertigo) or close to being statistically significant (tinnitus p = 0.08). One example is given below, which shows that the PSQI drops more rapidly at closer distances to the wind farm:

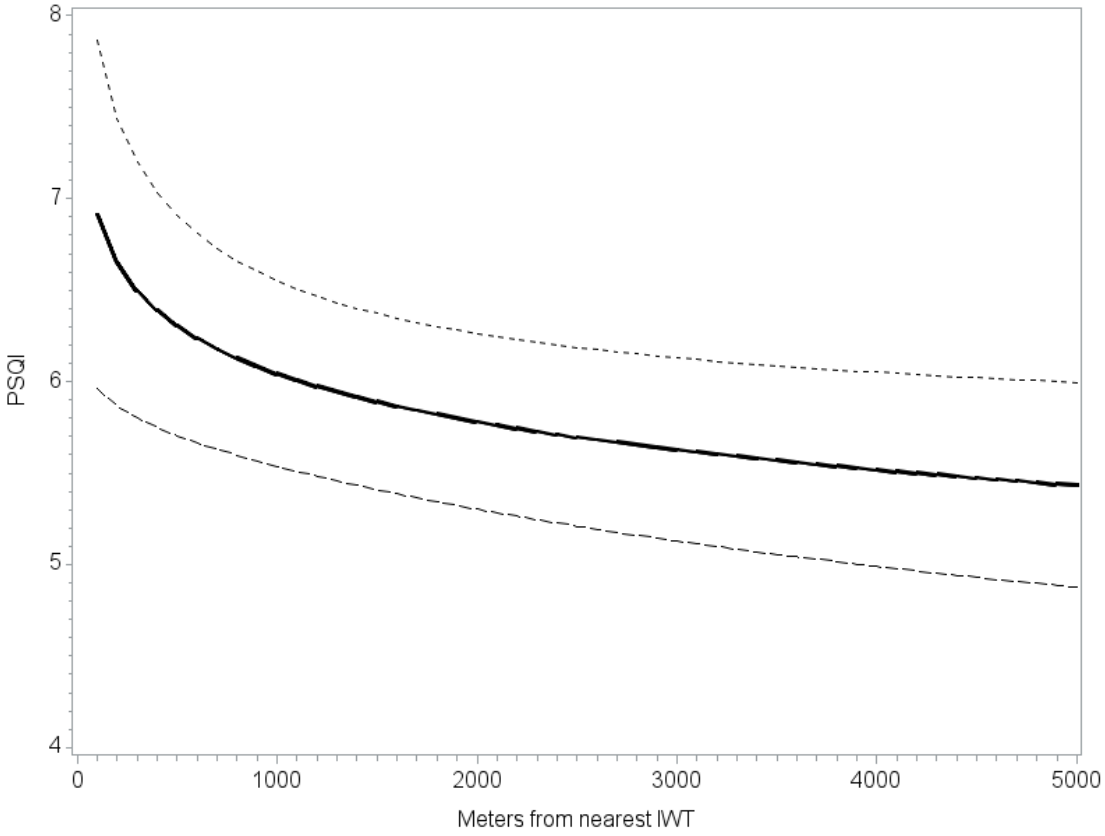

Figure 10: ***PSQI ln_dist Relationship (P=0.01). Graph shows modeled mean and upper and lower 95% confidence intervals***

While no data were presented for a similar analysis of WTS index, it is stated in the text that there was no association with the logarithm of distance, but vertigo was one of the variables used in this index.

No measures of risk are given for any of the other outcome variables used in the study, but there is a very large table (Table 13) which presents descriptive data for these outcomes across each of the 8 wind farms and for each of the quartiles of distance from a wind farm. The only statistical result given is a p-value for comparisons across the groups. The health outcomes for which the p-values are < 0.05 are for PSQI and vertigo. There was no significant difference across these groups for the following outcomes: the Physical Component Score (PCS) and Mental Component Score (MCS) of the SF-12, depression, SWLS, WTS index, headache, irritability score, concentration problems, nausea, undue tiredness, tinnitus or sleep quality.

Exposure group [21]	**Control group [22]**	**Measure of effect / effect size [23]** **95% CI [25]**	**Harms (NNH) [24]** **95% CI [25]**
See section 20 above.	N/A	No effect measures presented and no 95% CIs, apart from in the figures describing log distance and PSQI and vertigo.	N/A

Public health importance (1–4) [26]	**Relevance (1–5) [27]**
It is difficult to apply the rating scale on page 23 of the NHMRC Guidelines, as it is not suitable for this type of study, where many outcomes have been measured, but given the limitations of this research, the lowest ranking (4) seems most appropriate.	It is difficult to apply the rating scale on page 27 of the NHMRC Guidelines, as it is not suitable for this type of non-intervention study, but given the limitations of this research, the lowest ranking (5) seems most appropriate.

Comments [28]
While the serious limitations in design, execution, analysis and presentation make interpretation of these findings difficult, most health outcomes did not appear to have a relationship with distance from a wind farm and the two findings for which there appeared to be an association, this could be explained by chance, bias or confounding. Therefore, it is unlikely that the findings of this study have any clear implications in relation to the question of proximity of wind farms and human health.

Abbreviations: NR = not reported; NC = not calculable; N/A = not applicable

Pohl 2012

Reference [1]
Pohl J, Hubner G, Mohs A. Acceptance and stress effects of aircraft obstruction markings of wind turbines. *Energy Policy*. 2012;50:592-600.
Affiliation/source of funds [2] Martin Luther Universität, Halle Wittenberg, Germany. The study was funded by the Federal Ministry for Environment, Nature Conservation and Nuclear Safety, under a resolution by the Lower House of the German Parliament (Deutscher Bundestag), and by the State Agency for Agriculture, Environment and Rural Areas of Schleswig-Holstein.

Study design [3]	**Level of evidence [4]**	**Location/setting [5]**
Cross-sectional survey	IV	See [6] **Proximity/distance:** Less than 8 km from 13 wind farms with line of sight view of turbines.

Exposure description [6]	**Control(s) description [8]**
Wind farm details: 13 wind farms	No non-exposed groups were included.

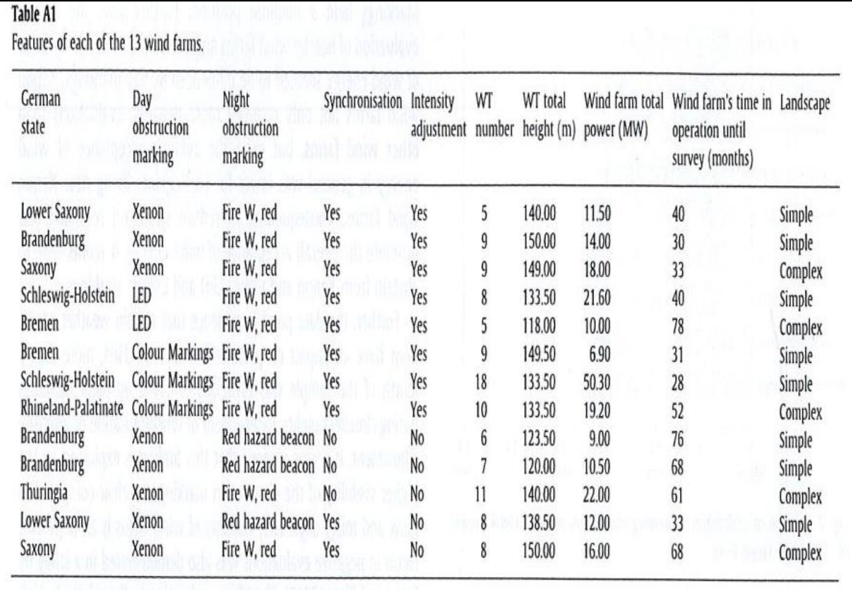

Table A1

Features of each of the 13 wind farms.

German state	Day obstruction marking	Night obstruction marking	Synchronisation	Intensity adjustment	WT number	WT total height (m)	Wind farm total power (MW)	Wind farm's time in operation until survey (months)	Landscape
Lower Saxony	Xenon	Fire W, red	Yes	Yes	5	140.00	11.50	40	Simple
Brandenburg	Xenon	Fire W, red	Yes	Yes	9	150.00	14.00	30	Simple
Saxony	Xenon	Fire W, red	Yes	Yes	9	149.00	18.00	33	Complex
Schleswig-Holstein	LED	Fire W, red	Yes	Yes	8	133.50	21.60	40	Simple
Bremen	LED	Fire W, red	Yes	Yes	5	118.00	10.00	78	Complex
Bremen	Colour Markings	Fire W, red	Yes	Yes	9	149.50	6.90	31	Simple
Schleswig-Holstein	Colour Markings	Fire W, red	Yes	Yes	18	133.50	50.30	28	Simple
Rhineland-Palatinate	Colour Markings	Fire W, red	Yes	Yes	10	133.50	19.20	52	Complex
Brandenburg	Xenon	Red hazard beacon	No	No	6	123.50	9.00	76	Simple
Brandenburg	Xenon	Red hazard beacon	No	No	7	120.00	10.50	68	Simple
Thuringia	Xenon	Fire W, red	No	No	11	140.00	22.00	61	Complex
Lower Saxony	Xenon	Red hazard beacon	Yes	No	8	138.50	12.00	33	Simple
Saxony	Xenon	Fire W, red	Yes	No	8	150.00	16.00	68	Complex

Specific exposure details:

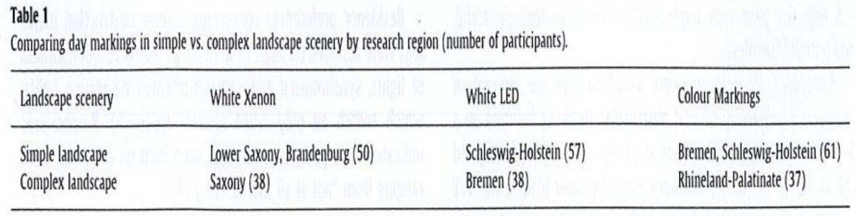

Table 1

Comparing day markings in simple vs. complex landscape scenery by research region (number of participants).

Landscape scenery	White Xenon	White LED	Colour Markings
Simple landscape	Lower Saxony, Brandenburg (50)	Schleswig-Holstein (57)	Bremen, Schleswig-Holstein (61)
Complex landscape	Saxony (38)	Bremen (38)	Rhineland-Palatinate (37)

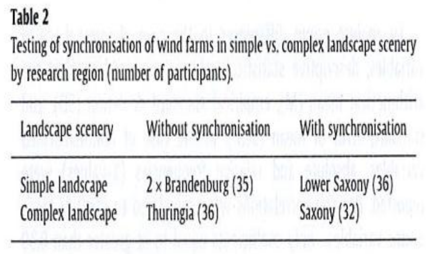

Table 2

Testing of synchronisation of wind farms in simple vs. complex landscape scenery by research region (number of participants).

Landscape scenery	Without synchronisation	With synchronisation
Simple landscape	2 × Brandenburg (35)	Lower Saxony (36)
Complex landscape	Thuringia (36)	Saxony (32)

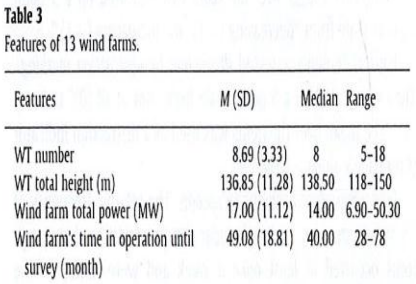

Table 3

Features of 13 wind farms.

Features	M (SD)	Median	Range
WT number	8.69 (3.33)	8	5-18
WT total height (m)	136.85 (11.28)	138.50	118-150
Wind farm total power (MW)	17.00 (11.12)	14.00	6.90-50.30
Wind farm's time in operation until survey (month)	49.08 (18.81)	40.00	28-78

Sample size [7]

N=281 respondents of first research design in 6 states

N=139 respondents of second research design in 4 states

Sample size [9] N/A

Population characteristics [10]

Exposure group: Up to 200 questionnaires were distributed to households around each wind farm. Response average rate was 24.8%. Average age was 51 years and average house duration was 21 years. Home owners were over-represented (85%), men participated (57%) more often than women. Majority were married (69%), 39% had completed junior high school qualifications and 38% held University entrance qualifications. The most frequently presented occupations were employees (33%), civil servants (11%), and self-employed persons (8%); 27% were retired. Of the respondents who worked, 31% also conducted their work at home. Only 4% worked in the wind business. About one-fourth of the participants had a household net income from 1001 to 2000 EUR, 26% from 2001 to 3000 EUR, and 16% from 3001 to 4000 EUR.

Length of follow-up [11] N/A

Outcome(s) measured and/or analyses undertaken [12]

The following stress indicators were used:

- General impact
- Annoyance
- Annoyance changes over the years
- Psychological and somatic symptoms
- Behaviour
- Coping response

INTERNAL VALIDITY

Confounding subscale [13]

Comment on sources of confounding: bias:

No potential confounders, such as SES, were considered in the analysis.

Bias subscale [14]

Comment on sources of bias:

High potential for sample selection bias due to low response rate. The study purpose was not masked and an incentive to take part was offered, so responder bias may have been enhanced.

EXTERNAL VALIDITY

Generalisability [15] Average response rate was 24.8%, potential for differences between the total exposed population and those that responded to the questionnaire.

Applicability [16] Unknown whether findings in Germany are comparable to those living near wind farms in Australia.

Reporting subscale [17]

Comment on quality of reporting: Overall quality of reporting was high but main deficit is that information was not presented on characteristics of non-responders.

Chance [18]

The possibility of spurious significant associations arising by chance cannot be excluded as multiple statistical tests were conducted.

Overall quality assessment (descriptive) [19]

This was a high quality cross-sectional study that made adjustments for confounders and bias, only low misclassification of outcomes is expected due to the methods and scales. However, the study intent was not masked and the relatively low response rate was not investigated.

RESULTS

Adverse effect outcomes [20]

We only report the annoyance outcomes as there were many other outcomes reported not directly related to health (e.g. strength of preference concerning obstruction marking):

While p-values were not reported, according to the study authors overall annoyance was rated significantly stronger for night (M = 1.32, SD = 1.38) than day markings (M = 0.97, SD = 1.21), independent of intensity adjustment.

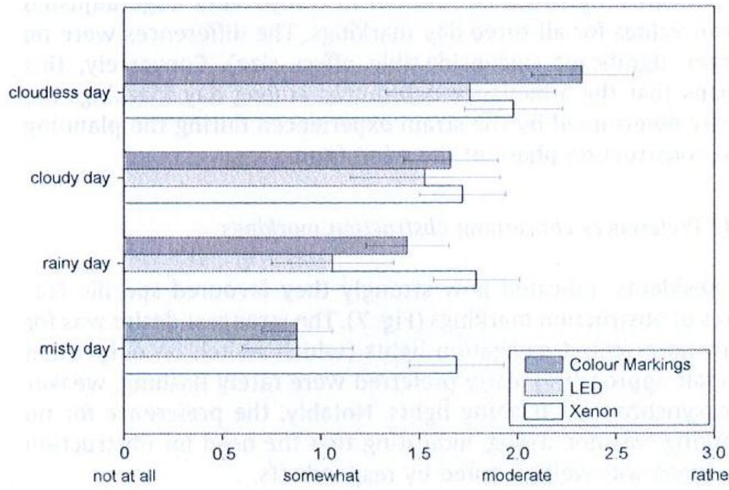

Fig. 2. Weather conditions characterised by particularly strong annoyance due to day marking (*M*7 SEM, scale range: 0–4).

In general, respondents reported annoyance to daytime obstruction markings was greatest on cloudless days and least on misty days. 29.7% of respondents reported strong annoyance in response to daytime obstruction markings and these respondents reported most annoyance by day markings on cloudless days, independent of marking type (Figure 2). Although annoyance was independent of marking type on cloudless days, on misty days, reported annoyance was higher for Xenon markings than other types of marking.

Almost all participants who reported being particularly annoyed by day markings also reported being annoyed by night markings as well (28.6%). In general annoyance was rated highest on cloudless nights, independent of intensity adjustment.

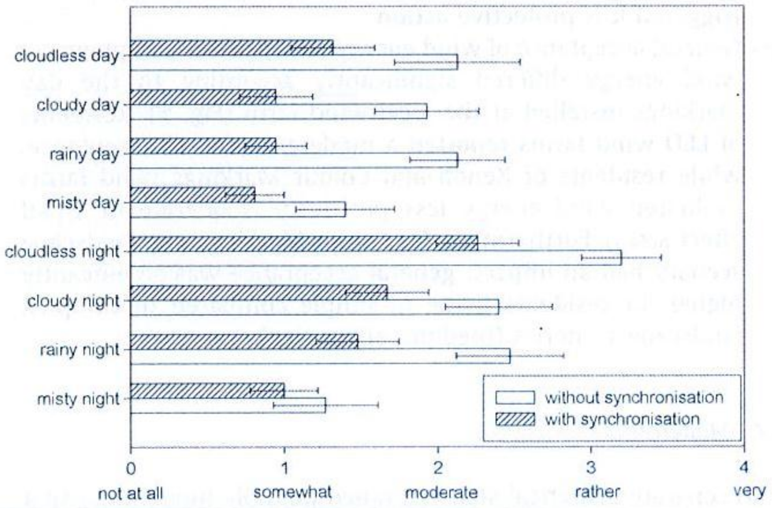

Fig. 3. Weather conditions with particularly strong annoyance caused by day and night marking for synchronised as well as non-synchronised wind farms without intensity adjustment (*M*7 SEM, scale range: 0–4).

For wind farms with markings not intensity adjusted for different visibility conditions, wind farms with synchronised markings attracted lower annoyance ratings (Figure 3). Of participants living near wind farms without intensity adjustment, annoyance was associated with particular weather conditions, especially cloudless nights. Misty conditions were associated with lower reported annoyance.

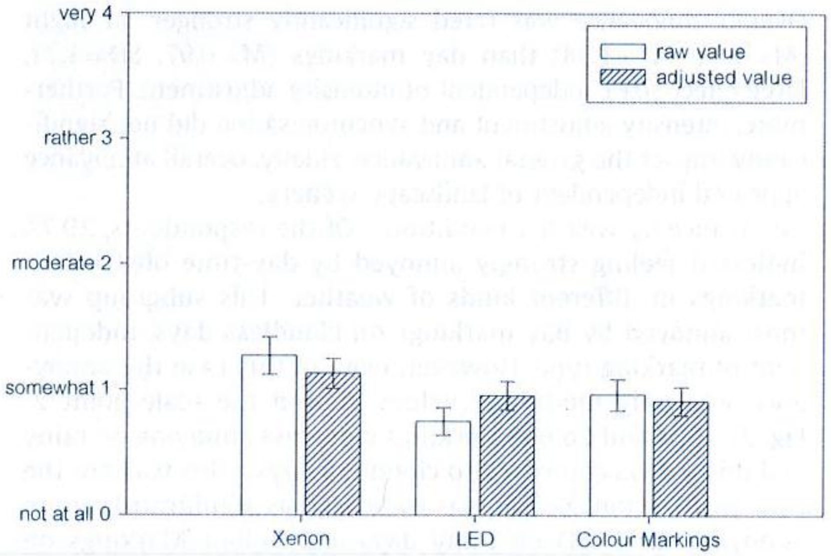

Fig. 6. Annoyance caused by day marking with (raw value) and without (adjusted value) consideration of the factor "strain during the planning and construction phase" (M7 SEM, scale range: 0–4).

Possible influence of stressors on the relationship between wind farm marking characteristics and annoyance was evaluated by considering participants' responses to questions which evaluated indications of stress. Of the more than 100 stress indicators evaluated, only one was associated: "strain during the planning and construction phase" (r > 0.30). Respondents reporting high strain during the planning and construction phase were more annoyed than respondents who did not report high strain during planning and construction. (Figure 6 shows the moderating effect of this strain variable on annoyance in relation to day markings.)

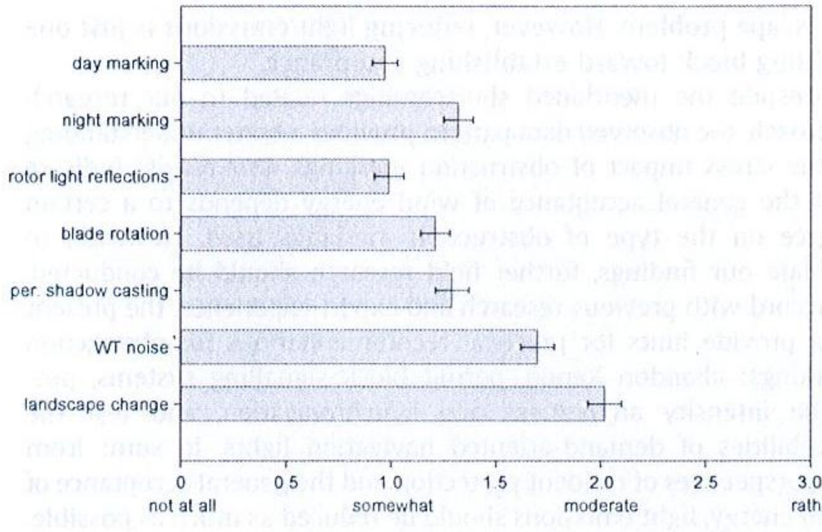

Fig. 8. Annoyance caused by obstruction markings compared to other WT emissions (total sample, M7 SEM, scale range: 0–4).

Of all wind farm "emissions", respondents reporting most annoyance associated with the change to the visual landscape, followed by noise with obstruction markings (day and night), reflections, blade rotation and shadow casting associated with lower degrees of annoyance (Figure 8).

Exposure group [21] See 'Adverse effect outcomes' [20]	**Control group [22]** N/A	**Measure of effect / effect size [23]** **95% CI [25]** See 'Adverse effect outcomes' [20]	**Harms (NNH) [24]** **95% CI [25]** See 'Adverse effect outcomes' [20]

Public health importance (1–4) [26]	**Relevance (1–5) [27]**
It is difficult to apply the rating scale on page 23 of the NHMRC Guidelines, as it is not suitable for this type of study, but given the limitations of this research, the lowest ranking (4) seems most appropriate.	It is difficult to apply the rating scale on page 27 of the NHMRC Guidelines, as it is not suitable for this type of study, but given the limitations of this research, the lowest ranking (5) seems most appropriate.

Comments [28]

This study was cross-sectional in design. This does not permit any conclusions regarding causation and health outcomes, in this case annoyance, from wind turbines. However, the results are consistent and the findings of the research robust. The study has limited capacity to inform the assessment of wind turbine obstruction markings as a cause of adverse health effects.

Abbreviations: NR = not reported; NC = not calculable; N/A = not applicable

Taylor 2013

Reference [1]

Taylor J, Eastwick C, Wilson R, Lawrence C. The influence of negative oriented personality traits on the effects of wind turbines. *Personality and Individual Differences.* 2013;54:338-43.

Affiliation/source of funds [2]

Mechanical, Materials and Manufacturing Engineering, University of Nottingham, Nottingham, UK

Department of Architecture and the Built Environment, University of Nottingham, Nottingham, UK

School of Psychology, University of Nottingham, Nottingham, UK

Funded by a National Environment Research Council Grant issued by UK Energy Research Centre

Study design [3]	**Level of evidence [4]**	**Location/setting [5]**
Cross-sectional survey	IV	Two cities in the Midlands of the UK. **Proximity/distance:** Households living within 500m of eight 0.6 kW micro turbine installations and within 1 km of four 5 kW small wind turbine installations.

Exposure description [6]

Wind farm details: Eight 0.6 kW micro turbine installations and four 5 kW small wind turbines.

Specific exposure details:

Modelled sound pressure in A-weighted decibels with a sound map with 1m grid over map area. Grid plane located 1.5 m above ground. Across all turbine sites, approximately 9.5% of those living within region 2, 13.5% living in region 1 and 10% living within region 0 responded.

Sample size [7]

Questionnaires sent to N = 1270 households with 138 completed survey returned (response rate 10.7%).

Control(s) description [8] No non-exposed groups were included in the survey.

Sample size [9] See population characteristics.

Population characteristics [10]

Exposure group: Any member of each household over the age of 18 could anonymously complete the survey. In total, 138 completed surveys were returned (age range of respondents = 20 - 95; mean age = 53.8, SD = 15.6; 1.4% were aged between 18 and 25, 12.3% between 26 and 35, 15.9% between 36 - 45, 23.2% between 46 - 55, 22.5% between 56 - 65, 12.3% between 66 - 75, 7.3% between 76 - 85 and 5.1% between 86 - 95. Response rate was 10.86% with 54.4% male.

Length of follow-up [11]

N/A

Outcome(s) measured and/or analyses undertaken [12] All outcomes measured by a self-reporting survey.

INTERNAL VALIDITY

Confounding subscale [13]

Comment on sources of confounding:
No adjustments were provided on likely confounders such as employment, economic benefit from turbines and background noise.

Bias subscale [14]

Comment on sources of bias:

The low response rate suggests that there may be sample selection bias. Masking of responders to the intent of the survey was not described.

EXTERNAL VALIDITY

Generalisability [15]

Survey mailed to a sample of subjects in the Midlands of the UK may not reflect the total population living within the 1 km distance from the wind farms.

Applicability [16]

Unknown whether the population characteristics and wind turbine exposures of the responders are comparable to those living near wind farms in Australia.

Reporting subscale [17]

Comment on quality of reporting:

Overall reporting good, but negative orientated personality not well defined and there was a very low participation rate.

Chance [18]

The possibility of spurious significant associations arising by chance cannot be excluded as multiple statistical tests were conducted.

Overall quality assessment (descriptive) [19]

Although the description of negative oriented personality traits was defined with some rigour, the results were not convincing given the relatively small response rate. The use of perceived turbine noise scale and its comparison to the calculated actual sound level (modelled) appeared plausible. However, discussion of confounders or bias was limited and the authors conceded that it was possible the responders were significantly different to the non-responders in terms of the variables measured.

RESULTS

Adverse effect outcomes [20]

Positive Affectivity (PA)

Negative Affectivity (NA)

Neuroticism (N)

Discomfort intolerance (F-disc)

Emotional intolerance (F-emot)

Non-specific somatic symptoms (SYMP)

Exposure group [21]

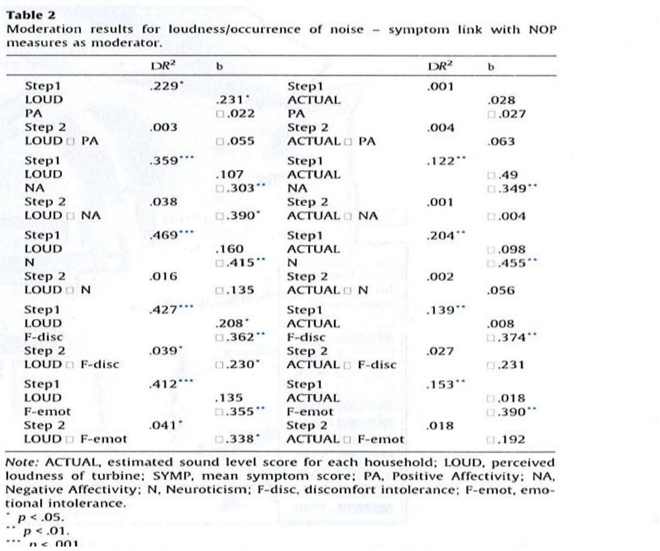

Table 2
Moderation results for loudness/occurrence of noise – symptom link with NOP measures as moderator.

	DR^2	b		DR^2	b
Step1	.229*		Step1	.001	
LOUD		.231*	ACTUAL		.028
PA		□.022	PA		□.027
Step 2	.003		Step 2	.004	
LOUD □ PA		□.055	ACTUAL □ PA		.063
Step1	.359***		Step1	.122**	
LOUD		.107	ACTUAL		□.49
NA		□.303**	NA		□.349**
Step 2	.038		Step 2	.001	
LOUD □ NA		□.390*	ACTUAL □ NA		□.004
Step1	.469***		Step1	.204**	
LOUD		.160	ACTUAL		□.098
N		□.415**	N		□.455**
Step 2	.016		Step 2	.002	
LOUD □ N		□.135	ACTUAL □ N		.056
Step1	.427***		Step1	.139**	
LOUD		.208*	ACTUAL		.008
F-disc		□.362**	F-disc		□.374**
Step 2	.039*		Step 2	.027	
LOUD □ F-disc		□.230*	ACTUAL □ F-disc		□.231
Step1	.412***		Step1	.153**	
LOUD		.135	ACTUAL		□.018
F-emot		□.355**	F-emot		□.390**
Step 2	.041*		Step 2	.018	
LOUD □ F-emot		□.338*	ACTUAL □ F-emot		□.192

Note: ACTUAL, estimated sound level score for each household; LOUD, perceived loudness of turbine; SYMP, mean symptom score; PA, Positive Affectivity; NA, Negative Affectivity; N, Neuroticism; F-disc, discomfort intolerance; F-emot, emotional intolerance.

* $p < .05$.

** $p < .01$.

*** $p < .001$

Respondents living in areas with low probability of hearing turbine noise had higher PA (mean = 2.86; SD = 1.05) than those living in areas with moderate (mean = 2.38; SD = 1.21) or high (1.97; SD = 1.04) probability of hearing turbine noise ($p \leq 0.05$) ($F_{2,118} = 6.40$; partial $g^2 = 0.10$; $p < 0.01$). There were no sex differences across the three regions ($\upsilon^2 = 2.11$; $p = 0.35$).

Control group [22]

N/A

Measure of effect / effect size [23]

95% CI [25]

NC

Harms (NNH) [24]

95% CI [25]

NC

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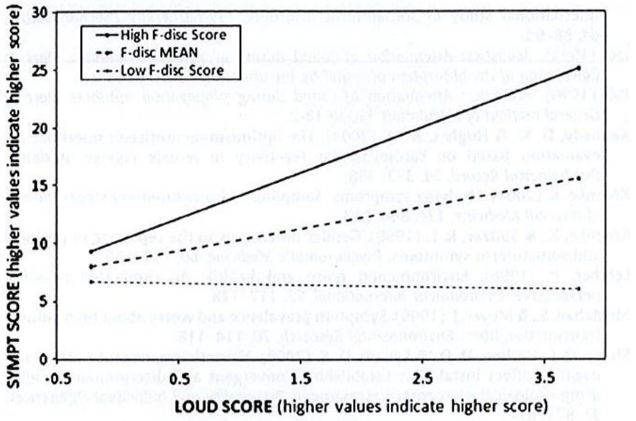

Fig. 2. Simple slopes for the loudness of noise–symptoms link with F-disc as moderator. <i>Note:</i> LOUD = perceived loudness of wind turbine noise, F-disc = discomfort intolerance; SYMP = mean symptom score.

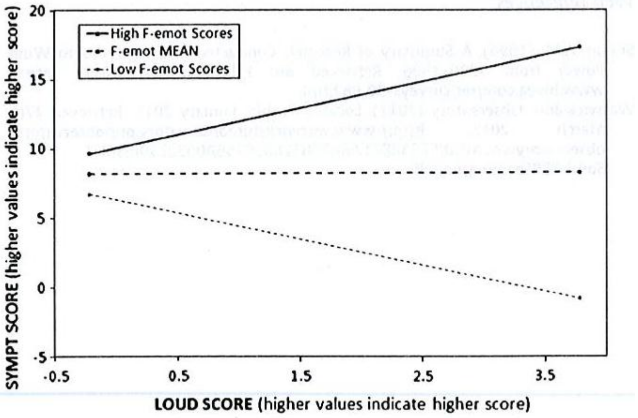

Fig. 3. Simple slopes for the loudness of noise–symptoms link with F-emot as moderator. <i>Note:</i> LOUD = perceived loudness of wind turbine noise, F-emot = emotional intolerance; SYMP = mean symptom score.

The simple slope analyses showed that the link between perceived loudness and symptoms reporting only occurred at high levels of discomfort intolerance (b = 3.954, t = 3.4815, p < 0.001, Fig 2) and emotional intolerance (b = 1.921, t = 1.677, p < 0.096, Fig 3). However, the simple slope analyses examining the link between perceived loudness and symptoms reporting did not reach significance at any level of NA. Calculated actual turbine noise did not affect symptom reporting directly or interactively.
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<tr>
<td>Public health importance (1–4) [26]
It is difficult to apply the rating scale on page 23 of the NHMRC Guidelines, as it is not suitable for this type of study, but given the limitations of this research, the lowest ranking (4) seems most appropriate.</td>
<td colspan="4">Relevance (1–5) [27]
It is difficult to apply the rating scale on page 27 of the NHMRC Guidelines, as it is not suitable for this type of study, but given the limitations of this research, the lowest ranking (5) seems most appropriate.</td>
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</table>

Comments [28] The overall finding was that perception of noise rather than actual noise exposure is important in predicting symptoms of ill-health, and that this relationship is stronger in those who have personality characterised by Negative Affect, and intolerance of negative emotion and events. However this finding is not convincing given the low response rate, lack of description of non-responders and use of modelled noise exposure instead of actual measurements for relatively small wind turbines. 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; N/A = not applicable

Yano 2013

Reference [1] Yano T, Kuwano S, Kageyama T, Sueka S, Tachibana H. Dose-response relationship for wind turbine noise in Japan. *42nd International Congress and Exposition on Noise Control Engineering*, Innsbruck, Austria, 15-18 September 2013.
Affiliation/source of funds [2] Osaka University, Japan; Kumamoto University, Japan; Oita University of Nursing and Health Sciences, Japan; Sueoka Professional Engineer Office, Japan; Chiba Institute of Technology, Japan. Funding from the Ministry of the Environment of Japan (Project No. S2-11).

Study design [3]	**Level of evidence [4]**	**Location/setting [5]**
Cross-sectional study.	IV	Various sites from Hokkaido to Okinawa in Japan. **Proximity/distance:** Respondents' houses were from 90 to 1466 m apart from the closest wind turbine.

Exposure description [6]	**Control(s) description [8]**
Wind farm details: 36 "target sites" were identified with audible wind turbine noise from Hokkaido to Okinawa, Japan. Regular electricity generation of wind turbines was from 400 kW to 3,000 kW, mainly more than 1,500 kW. **Specific exposure details:** The average sound pressure levels $L_{Aeq,n}$ in decibels was measured with sound levels ranging from 26 dB to 50 dB. Nine sites were observed to have strong sea wave sound during winter. **Sample size [7]** 747 respondents in 'target site' areas were approached by door knocking, of whom 49% participated (n=~ 366, calculated).	Residents at 16 control sites where wind turbine noise is inaudible but no turbines were visible. **Sample size [9]** 332 control site respondents were approached by door knocking, of whom 45% responded (n= ~145, calculated).

Population characteristics [10]

Exposure group

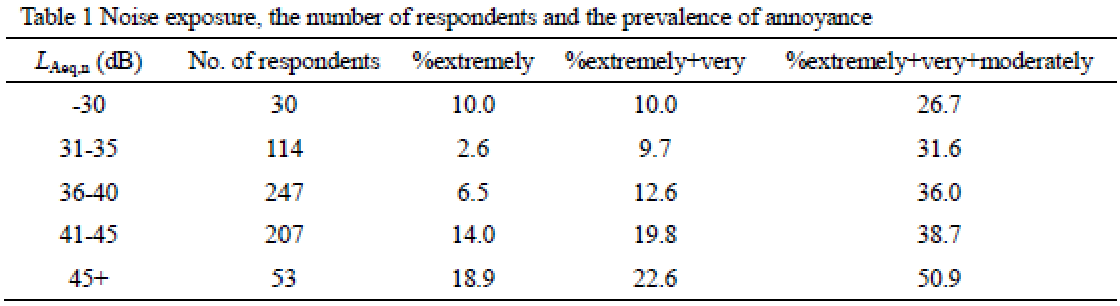


Table 1 Noise exposure, the number of respondents and the prevalence of annoyance

$L_{\text{Aeq,n}}$ (dB)	No. of respondents	%extremely	%extremely+very	%extremely+very+moderately
-30	30	10.0	10.0	26.7
31-35	114	2.6	9.7	31.6
36-40	247	6.5	12.6	36.0
41-45	207	14.0	19.8	38.7
45+	53	18.9	22.6	50.9

Length of follow-up [11]

N/a cross-sectional study.

Outcome(s) measured and/or analyses undertaken [12]

Annoyance related to wind turbine noise was evaluated by ICBEN 5-point verbal scale: extremely, very, moderately, slightly or not at all. Analysis metric was created by combining moderately, very and extremely annoyed by wind turbine noise (see Kuwano 2013, appendix).

INTERNAL VALIDITY

Confounding subscale [13]

Comment on sources of confounding:
No mention of addressing of confounders.

Bias subscale [14]

Comment on sources of bias:
Poor response rate

EXTERNAL VALIDITY

Generalisability [15]

Cross-sectional survey limits ability to determine causality.

Demographics not reported in detail in present paper but see Kuwano et al (2013) for detailed about this survey sample and its generalisability. Age distribution and cultural expectations of elderly Japanese likely to limit generalisability to Australia.

Applicability [16]

Population density in wind turbine areas surveyed not clear but likely more dense than wind turbine areas in Australia which are typically rural and relatively sparsely populated. Likely differences in background noise and sound paths due to different environments.

Reporting subscale [17]

Comment on quality of reporting:
Key details unreported, for example full description of the wind turbine and control areas (urban/rural, population density) and detailed recruitment methodology.

Chance [18]

Large number of statistical tests indicates possibility for chance findings however directionality of dose-response curves are as expected. No mention of statistical adjustments for chance.

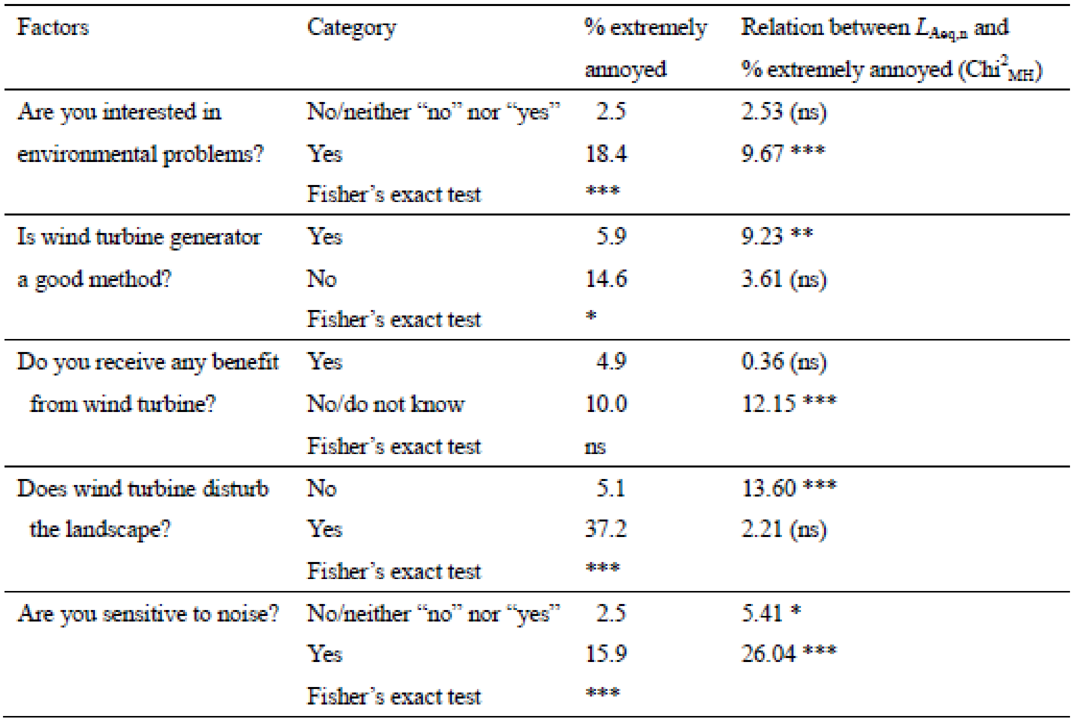
Overall quality assessment (descriptive) [19]

Possibility of exposure misclassification (exposure time not evaluated), outcome misclassification (some questions not validated instruments) sample selection bias (low response rate), confounding and reporting bias (unclear if participants were blinded to purpose of study, unlikely to be blinded to purpose of the particular question used to assess the outcome in this analysis). Conclusions based on sea wave noise speculative and not clearly supported by systematically collected data. Sensitivity to noise poorly defined.

RESULTS

Adverse effect outcomes [20]

Table 2 Relation between $L_{Aeq,n}$ and % extremely annoyed per subgroup



Factors	Category	% extremely annoyed	Relation between $L_{Aeq,n}$ and % extremely annoyed (Chi^2_{MH})
Are you interested in environmental problems?	No/neither "no" nor "yes"	2.5	2.53 (ns)
	Yes	18.4	9.67 ***
	Fisher's exact test	***	
Is wind turbine generator a good method?	Yes	5.9	9.23 **
	No	14.6	3.61 (ns)
	Fisher's exact test	*	
Do you receive any benefit from wind turbine?	Yes	4.9	0.36 (ns)
	No/do not know	10.0	12.15 ***
	Fisher's exact test	ns	
Does wind turbine disturb the landscape?	No	5.1	13.60 ***
	Yes	37.2	2.21 (ns)
	Fisher's exact test	***	
Are you sensitive to noise?	No/neither "no" nor "yes"	2.5	5.41 *
	Yes	15.9	26.04 ***
	Fisher's exact test	***	

Respondents were significantly more likely to report being extremely annoyed by wind turbines if they reported being interested in environmental problems, believed that wind turbines were not a good method and if they viewed wind turbines as a landscape disturbance. Self-reported sensitivity to noise was also associated with greater propensity to report being extremely annoyed by wind turbines.

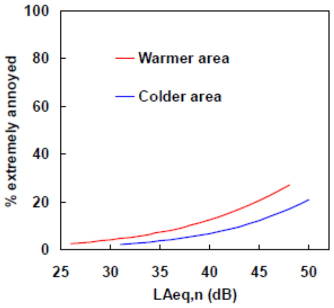


Figure 3 Comparison of dose-response relationships between colder and warmer areas

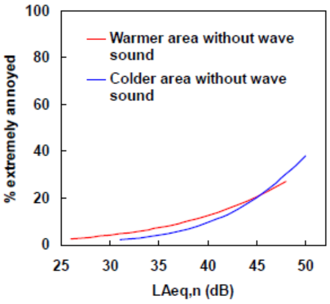


Figure 4 Comparison of dose-response relationships between colder and warmer areas without wave sound

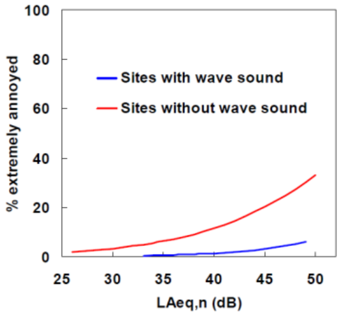


Figure 5 Effects of sea wave sound on dose-response relationships for wind turbine noise annoyance

Using multiple logistic regression analyses using probability of extremely annoyed or not as the dependent variable, no significant differences were found for colder and warmer areas (p > 0.05), however similar analyses showed that sea wave sound was inversely associated with probability of extremely annoyed

(p < 0.005) and the authors suggested this was because of masking of turbine noise by sea wave sound.			
Exposure group [21] See 'Adverse effect outcomes' [20].	**Control group [22]** See 'Adverse effect outcomes' [20].	**Measure of effect / effect size [23]** **95% CI [25]** See 'Adverse effect outcomes' [20].	**Harms (NNH) [24]** **95% CI [25]** See 'Adverse effect outcomes' [20].
Public health importance (1–4) [26] It is difficult to apply the rating scale on page 23 of the NHMRC Guidelines, as it is not suitable for this type of study, where many outcomes have been measured, but given the limitations of this research, the lowest ranking (4) seems most appropriate.		**Relevance (1–5) [27]** It is difficult to apply the rating scale on page 27 of the NHMRC Guidelines, as it is not suitable for this type of non-intervention study, but given the limitations of this research, the lowest ranking (5) seems most appropriate.	
Comments [28] This cross-sectional survey does not permit any conclusions about causation because it cannot be determined that exposures precede outcomes. Self-reported exposures and outcomes are likely to be subject to reporting bias and recruitment bias is also likely. Overall noise profile of control areas is likely to be systematically different to wind turbine areas in ways other than presence of turbines. Over-recruitment of elderly residents limits generalisability to broader population. Although context is poorly described, differences between Japanese and Australian contexts likely limit generalisability to Australia. This study has very limited capacity to inform the assessment of wind turbine noise of adverse health effects.			

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.

Australian Government
National Health and Medical Research Council

NHMRC Statement: Evidence on Wind Farms and Human Health

Examining whether wind farm emissions may affect human health is complex, as both the character of the emissions and individual perceptions of them are highly variable.

After careful consideration and deliberation of the body of evidence, NHMRC concludes that there is currently no consistent evidence that wind farms cause adverse health effects in humans.

Given the poor quality of current direct evidence and the concern expressed by some members of the community, high quality research into possible health effects of wind farms, particularly within 1,500 metres (m), is warranted.

This Statement updates previous work by NHMRC and is based on the findings of a comprehensive independent assessment of the scientific evidence on wind farms and human health, which is summarised in the *NHMRC Information Paper: Evidence on Wind Farms and Human Health*.

The Statement reflects the results and limitations of the studies that considered the possible relationships between wind farm emissions and health outcomes (direct evidence) and also takes into account evidence on the health effects of similar emissions from other sources (parallel evidence).

There is no direct evidence that exposure to wind farm noise affects physical or mental health. While exposure to environmental noise is associated with health effects, these effects occur at much higher levels of noise than are likely to be perceived by people living in close proximity to wind farms in Australia. The parallel evidence assessed suggests that there are unlikely to be any significant effects on physical or mental health at distances greater than 1,500 m from wind farms.

There is consistent but poor quality direct evidence that wind farm noise is associated with annoyance. While the parallel evidence suggests that prolonged noise-related annoyance may result in stress, which may be a risk factor for cardiovascular disease, annoyance was not consistently defined in the studies and a range of other factors are possible explanations for the association observed.

There is less consistent, poor quality direct evidence of an association between sleep disturbance and wind farm noise. However, sleep disturbance was not objectively measured in the studies and a range of other factors are possible explanations for the association observed. While chronic sleep disturbance is known to affect health, the parallel evidence suggests that wind farm noise is unlikely to disturb sleep at distances of more than 1,500 m from wind farms.

There is no direct evidence that considered the possible effects on health of infrasound or low frequency noise from wind farms. Exposure to infrasound and low-frequency noise in a laboratory setting has few, if any, effects on body functions. However, this exposure did not replicate all of the characteristics of wind farm noise as it has generally been at much higher levels and of short duration.

Although individuals may perceive aspects of wind farm noise at greater distances, it is unlikely that it will be disturbing at distances of more than 1,500 m. Noise from wind farms, including its content of low-frequency noise and infrasound, is similar to noise from many other natural and human-made sources.

NHMRC urges authorities with responsibility for regulating wind farms to undertake appropriate planning, in consultation with communities, and be cognisant of evidence emerging from research.

Although it is unlikely that there are significant health effects at a distance of more than 1,500 m from wind farms, concern has been expressed by people living near wind farms about perceived impacts on their health. NHMRC recommends that any person experiencing health problems consult their General Practitioner.

Given these reported experiences and the limited reliable evidence, NHMRC considers that further, higher quality, research is warranted. NHMRC will issue a Targeted Call for Research into wind farms and human health to encourage Australia's best researchers to undertake independent, high quality research investigating possible health effects and their causes, particularly within 1,500 m from a wind farm.

Further information can be found in the NHMRC Information Paper and on the NHMRC website at: www.nhmrc.gov.au/your-health/wind-farms-and-human-health.

February 2015
NHMRC ref # EH57

THE UNIVERSITY
of ADELAIDE

Systematic review of the human health effects of wind farms

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The National Health and Medical Research Council commissioned this research from:

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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.

CONTENTS

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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.

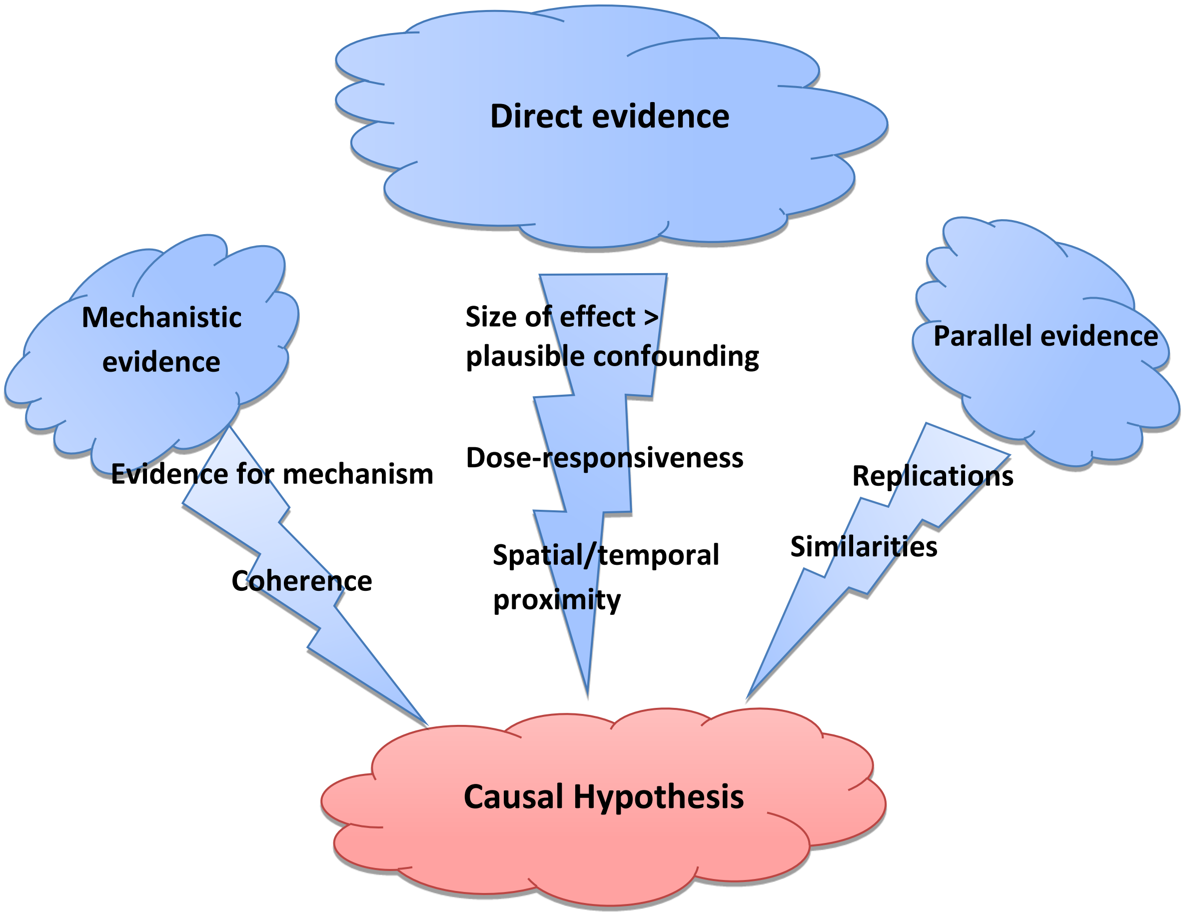

Figure ES. 1 Use of different types of evidence to support determination of causation (adapted from Howick, Glasziou and Aronson, 2009)

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)

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[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 &

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[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

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[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?

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[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'.

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[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

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[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)	1) PubMed: "Noise/adverse effects"[Mesh] AND (Cohort studies[Mesh] OR cohort analysis) 2) PubMed: "Noise/adverse effects"[Mesh] AND systematic[sb] 3) Embase: 'noise injury'/exp AND - 'human'/de AND ('article'/it OR 'review'/it) AND [english]/lim - ('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] Limited to studies of humans and those in English No chronological limits
Infrasound (less than 20 Hz)		
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) 2) PubMed: ("shadow flicker" OR photic stimulation/adverse effects OR seizures/etiology OR epilepsy	

	reflex/etiology) AND systematic[sb] 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 • 'human'/de AND ('article'/it OR 'review'/it) AND [english]/lim • ('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) 2) PubMed: (“Electromagnetic fields/adverse effects”[Mesh] AND “electric power supplies/adverse effects”[Mesh]) AND systematic[sb] 3) Embase: (‘Electromagnetic field’/exp AND ‘power supply’/exp) AND • 'human'/de AND ('article'/it OR 'review'/it)) AND [english]/lim • ('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] 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

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[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]
Population/participants	People living within proximity of a wind farm / wind turbines *<u>Subgroup analysis</u> by distance from wind farm / wind turbine*
Exposure	Physical emissions produced by wind farms / wind turbines, specifically: • noise (≥20 Hz) • infrasound (<20 Hz) • shadow flicker (photosensitivity >3 Hz) • electromagnetic radiation *<u>Subgroup analysis</u> by level of exposure[b] for each of these exposures.*
Comparator / 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
Outcomes	Any reported adverse health effects
Time	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

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[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.

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[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.

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[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 *[evidence assesses impact of exposure on health outcomes]*	• Size of health effect not attributable to plausible confounding[21] • Appropriate temporal proximity—cause precedes health effect and effect occurs after a plausible interval • Appropriate spatial proximity—health effect occurs at the same location as the exposure • Dose-responsiveness—health effect changes according the intensity of the exposure • Reversibility—the health effect possibly produced by an exposure can be reversed by its removal
Mechanistic *[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 • Coherence—proposed mechanism of action (causal hypothesis) is consistent with, and is not contradicted by, other current scientific knowledge
Parallel *[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 • 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.

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[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).

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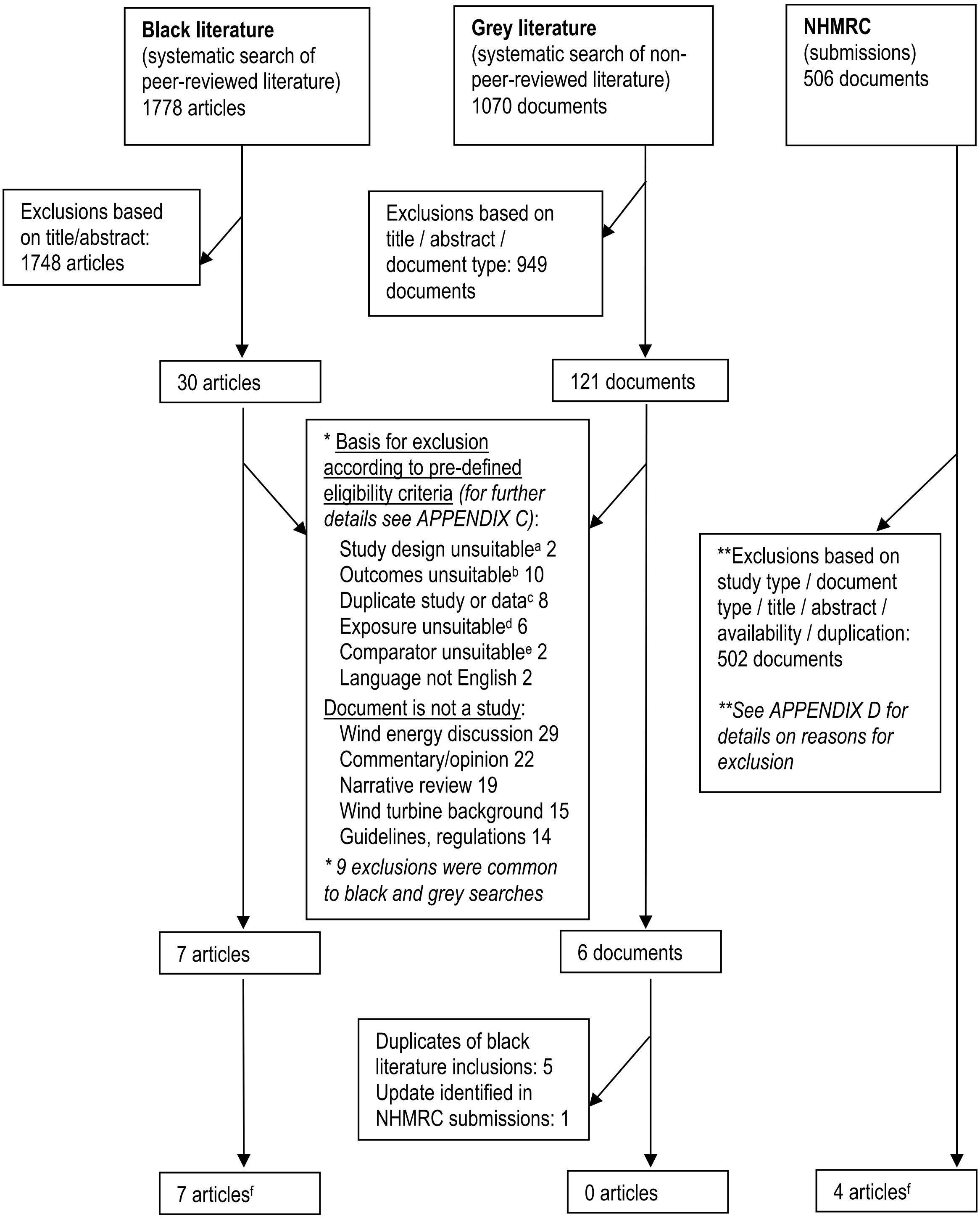
[24] An English translation was identified and the reference was found not to be a study.



[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) Pedersen et al. (2009) 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) Pedersen (2011)

SWE-05	Pedersen and Persson Waye (2007)	Sweden	Pedersen and Larsman (2008) 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** **NL-07** **Bakker et al. (2012)**	**Ontario, Canada** **Krogh et al. (2011)**	**Australia** **Morris (2012)**	**Maine, USA** **Nissenbaum, Aramini and Hanning (2012)**	**Sweden** **SWE-00** **Pedersen and Persson Waye (2004)**	**Sweden** **SWE-05** **Pedersen and Persson Waye (2007)**	**New Zealand** **Shepherd et al. (2011)**
Study type	Cross-sectional self-report questionnaire N=725	Cross-sectional self-report questionnaire N=109	Cross-sectional self-report questionnaire N=93 households	Cross-sectional self-report questionnaire N=79	Cross-sectional self-report questionnaire N=351	Cross-sectional self-report questionnaire N=754	Cross-sectional self-report questionnaire N=198
Articles contributing additional data[a]	**Van den Berg et al. (2008)** **Pedersen et al. (2009)** **Pedersen (2011)**				**Pedersen and Larsman (2008)** **Pedersen (2011)**	**(Pedersen and Larsman (2008)** **Pedersen (2011)**	
Characteristics of population and study setting	Dutch population living in rural and urban settings within 2.5 km of wind turbines 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 No population characteristics reported	Residents of Mars Hill and Vinalhaven Maine, USA – locations of wind farms Mean age of 'far' group older than	Residents of southern Sweden living 150–1199 m from wind turbines 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 Age distribution by

Study identification	**The Netherlands** **NL-07** **Bakker et al. (2012)**	**Ontario, Canada Krogh et al. (2011)**	**Australia** **Morris (2012)**	**Maine, USA** **Nissenbaum, Aramini and Hanning (2012)**	**Sweden** **SWE-00** **Pedersen and Persson Waye (2004)**	**Sweden** **SWE-05** **Pedersen and Persson Waye (2007)**	**New Zealand** **Shepherd et al. (2011)**
	% male = 51	Fluency in English required Mean age = 52 years % male = 48		'near' group % male 'near' group = 58 % male 'far' group = 44	% male = 42	Mean proximity to turbines = 780±233 m Mean age = 51±15 years % male = 44	group given in APPENDIX B % male 'near' group = 41 % male 'far' group = 41
Exposure considered	Modelled sound pressure level outside residences near wind turbines in dB(A) Averaged over time with 8 m/s downwind; range = 21–54 dB(A), mean = 35 dB(A) Grouped into five dB(A) categories:	Exposure to wind turbines (noise levels not reported) All residences located within 2.4 km of wind turbines Distance from turbine: 350–490 m, 24%; 55–673 m, 23%;	Exposure to wind turbines (noise levels not reported) 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 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 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 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)) 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** **NL-07** **Bakker et al. (2012)**	**Ontario, Canada Krogh et al. (2011)**	**Australia** **Morris (2012)**	**Maine, USA** **Nissenbaum, Aramini and Hanning (2012)**	**Sweden** **SWE-00** **Pedersen and Persson Waye (2004)**	**Sweden** **SWE-05** **Pedersen and Persson Waye (2007)**	**New Zealand** **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 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 **Van den Berg et al. (2008):** (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 **Pedersen & Larsman (2008):** Influence of noise level, visual attitude and general attitude on annoyance **Pedersen (2011):** Annoyance, sleep	Perception of noise; annoyance with noise **Pedersen and Larsman (2008):** Influence of noise level, visual attitude and general attitude on annoyance **Pedersen (2011):** Annoyance, sleep interruption,	QoL as per WHO quality of life scale (brief version)—WHOQOL-BREF—which includes self-reported general health Additional outcomes on amenity, annoyance, noise sensitivity, neighbourhood problems

Study identification	**The Netherlands** **NL-07** **Bakker et al. (2012)**	**Ontario, Canada Krogh et al. (2011)**	**Australia** **Morris (2012)**	**Maine, USA** **Nissenbaum, Aramini and Hanning (2012)**	**Sweden** **SWE-00** **Pedersen and Persson Waye (2004)**	**Sweden** **SWE-05** **Pedersen and Persson Waye (2007)**	**New Zealand** **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 **Pedersen et al. (2009):** Response (do not notice/annoyance) to wind turbine noise outdoors and indoors, and attitude to wind turbines **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	

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	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? **[exposure**	Partly—in terms of place *(and in personal characteristics in van den Berg et al. 2008, see APPENDIX B)* Personal	Partly—in terms of place Personal characteristics: Age and gender only personal characteristics	Partly—in terms of place Personal characteristics: None reported Place: All residents	Partly—in terms of place Personal characteristics: Age and gender only personal characteristics	Partly—in terms of personal characteristics and place Personal characteristics: Age, gender, residence,	Partly—in terms of personal characteristics and place Personal characteristics: Age, gender, residence type and	Partly—in terms of personal characteristics and place Personal characteristics: Age, gender, education,

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

Study identification	**The Netherlands** **NL-07** **Bakker et al. (2012)**	**Ontario, Canada Krogh et al. (2011)**	**Australia** **Morris (2012)**	**Maine, USA** **Nissenbaum, Aramini and Hanning (2012)**	**Sweden** **SWE-00** **Pedersen and Persson Waye (2004)**	**Sweden** **SWE-05** **Pedersen and Persson Waye (2007)**	**New Zealand** **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? **[selection bias]**	63% of those who received a questionnaire did not complete and return it Sampling area determined by distance from wind turbines High non-participation rate indicates a high	Not reported what proportion did not complete and return questionnaire Sampling area was chosen because adverse health effects had been reported there Multiple adults from same	60% of questionnaires delivered to households were not returned Sampling area determined by distance from wind turbines High non-participation rate indicates a high	Of those who received a questionnaire: 'Near' group = 42% did not complete and return it 'Far' group = not reported what proportion did not complete and return it Sampling area	32% of those who received a questionnaire did not complete and return it 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 Sampling area determined by distance from wind turbines and type of terrain Moderate non-participation rate	Of those who received a questionnaire: 'Exposed' group = 66% did not complete and return it Control group = 68% did not complete and return it Sampling area

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	probability of selection bias which may vary depending on wind turbine exposure. 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 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 High non-participation rate indicates a high probability of selection bias, so characteristics of sample may vary depending on wind turbine exposure.

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	Pedersen et al. (2009): 63% 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? **[outcome misclassification]**	Partly—GHQ-12 used for some outcomes GHQ-12 is a valid measure of psychiatric ill health Remaining components of	No The survey form designed by Harry (2007) was reproduced and used for this survey Health outcomes were self-reported	No A purpose-designed form was used for this survey Health outcomes were self-reported	Partly—PSQI, ESS, SF-36v2 used PSQI, ESS, SF-36v2 considered to be standardised and valid measures Other parts of the questionnaire were purpose-	No Assumed to be a purpose-designed survey created by the study authors. Health outcomes were self-reported.	No Assumed to be a purpose-designed survey created by the study authors. Health outcomes were self-reported.	Partly—WHOQOL-BREF used Used validated WHO quality of life scale (brief version) (WHOQOL-BREF) with following components: physical,

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	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. Health outcomes were self-reported			designed for the study. Health outcomes were self-reported.			psychological, social and environmental 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

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		others, were not included in the analysis					
Recall bias?	Uncertain Study intent was masked for respondents—unknown how effective this was	Likely Intent of survey not masked – "affected" people were encouraged to participate	Likely Intent of survey not masked	Likely Intent of survey not masked	Uncertain Study intent was masked for respondents—unknown how effective this was	Uncertain Study intent was masked for respondents—unknown how effective this was	Uncertain Study intent was masked for respondents—unknown how effective this was
Confounding? (other factors that could affect the outcomes)	Analyses adjusted for: Age, gender, employment, terrain, urbanisation, economic benefit from turbines, background noise, noise sensitivity, attitude to turbines and	Analyses adjusted for: Gender in some analyses Other plausible confounders not addressed: Economic factors, age, chronic disease and risk factors for chronic	Analyses adjusted for: Nil Other plausible confounders not addressed: Economic factors, age, gender, chronic disease and risk factors for chronic disease,	Analyses adjusted for: Age, gender, site, and household clustering Other plausible confounders not addressed: Economic factors, chronic disease and risk factors for	Analyses adjusted for: Age, gender, noise sensitivity, visual impact, attitude to turbines in some analyses Other plausible confounders not addressed: Economic factors,	Analyses adjusted for: Age, gender, employment, housing, residence duration, terrain, urbanisation, background noise, noise sensitivity, visual impact, attitude to turbines	Analyses adjusted for: Length of residence (and participants selected from geographic and socio-economic matched areas) Other plausible confounders not

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	turbine visibility (covariates varied between analyses) Other plausible confounders not addressed: 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) Other plausible confounders not addressed: Economic factors, chronic disease and risk factors for chronic disease, occupation, education.	addressed: 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 5 cases excluded

Study identification	**The Netherlands** **NL-07** **Bakker et al. (2012)**	**Ontario, Canada Krogh et al. (2011)**	**Australia** **Morris (2012)**	**Maine, USA** **Nissenbaum, Aramini and Hanning (2012)**	**Sweden** **SWE-00** **Pedersen and Persson Waye (2004)**	**Sweden** **SWE-05** **Pedersen and Persson Waye (2007)**	**New Zealand** **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** High risk of: • exposure misclassification • selection bias • significant associations due to chance Potential for: • outcome misclassification • recall bias • confounding	**Poor** High risk of: • exposure misclassification • outcome misclassification • recall bias • selection bias • confounding • significant associations due to chance	**Poor** High risk of: • exposure misclassification • selection bias • outcome misclassification • recall bias • confounding	**Poor** High risk of: • exposure misclassification • recall bias • selection bias • confounding • significant associations due to chance Potential for: • outcome misclassification	**Poor** High risk of: • exposure misclassification • outcome misclassification • confounding Potential for: • recall bias	**Poor** High risk of: • exposure misclassification • selection bias • outcome misclassification • significant associations due to chance Potential for: • recall bias • confounding	**Poor** High risk of: • exposure misclassification • selection bias • confounding Potential for: • outcome misclassification • 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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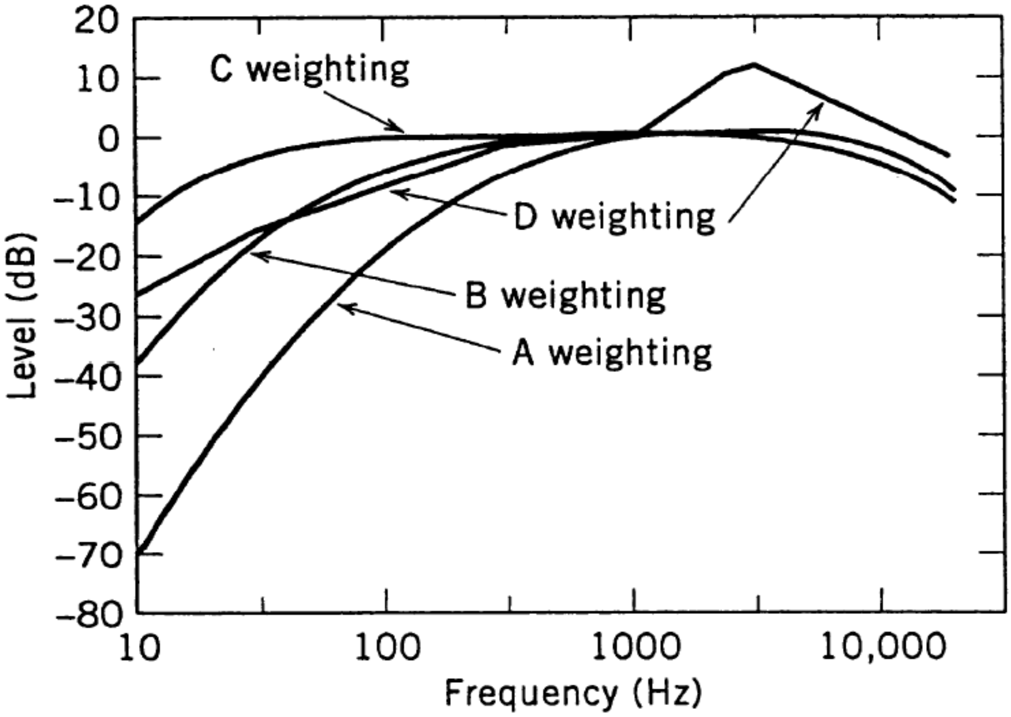
[25] Frequency is the number of sound waves/cycles passing a given point per second and is measured is cycles per second (cps), also called hertz (Hz).

[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 (20×10^{-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.

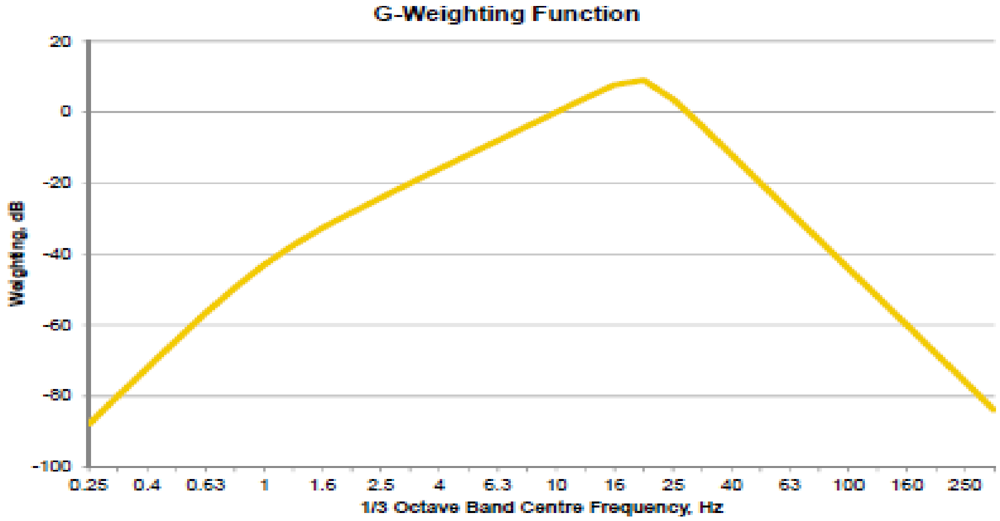


Source: Figure 1.3.7, Jacobsen et al. (2011)

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.

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[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).

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[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 α is the frequency-dependent sound absorption coefficient (α = 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 ∑ is from turbine $i = 1$ to N^{th} turbine, and L_i is the sound power of the i^{th} turbine.

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[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.

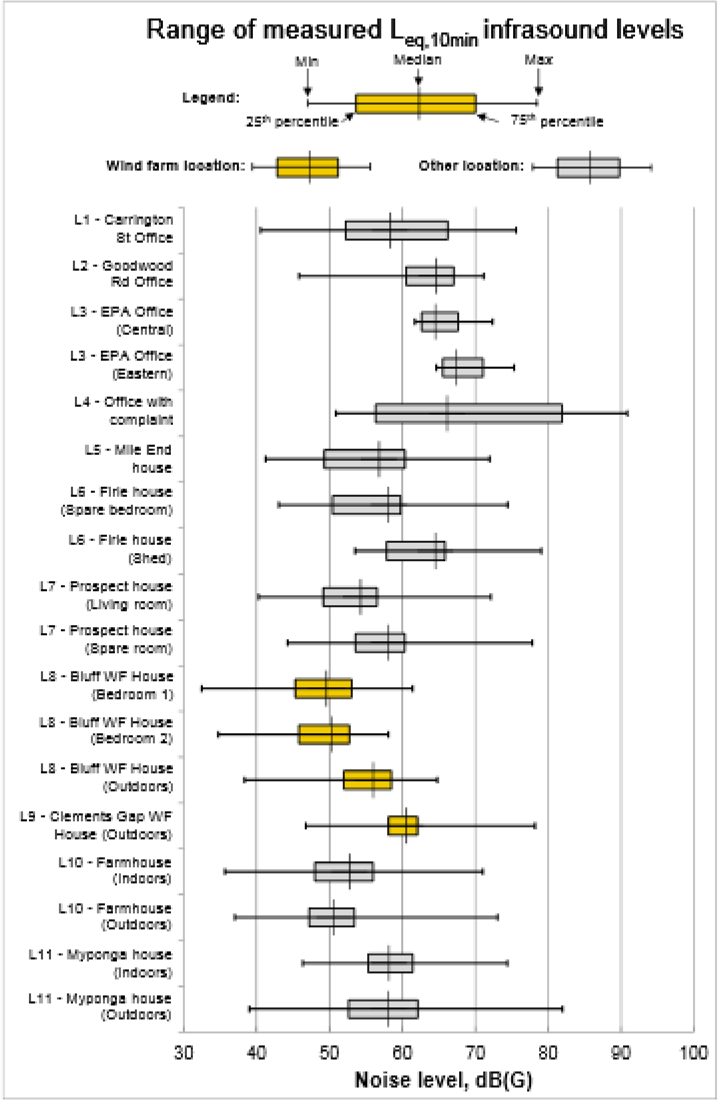
The Environmental Agency of North Rhein-Westphalia (LNW 2002) provided some data on SPLs by distance from a single wind turbine with a sound power level of 103 dB(A). Details as reproduced by Ellenbogen et al. (2012) are as follows:

- 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. 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 Economic benefits (no; yes) Age (years) Gender (male; female)	1.02 (0.99, 1.06) 0.74 (0.41, 1.34) 0.99 (0.99, 1.00) 1.12 (0.78, 1.58)
	Stress scores (<0; ≥0.01) (n=656)	Sound levels Economic benefits (no; yes) Age (years) Gender (male; female)	1.01 (0.98, 1.04) 0.61 (0.35, 1.07) **0.98 (0.97, 0.99)** 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]** **OR (95%CI)** N[c]=319–333	**SWE-05[a]** **OR (95%CI)** N[c]=720–744	**NL-07** **OR (95%CI) or %** N[c]=639–678
Comparison of studies NL-07, SWE-00 and SWE-05 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 Van den Berg et al. (2008) The Netherlands	Difficulties in falling asleep	-	-	N=710 <30 dB(A): 36% 30–35 dB(A): 31% 35–40 dB(A): 28% 40–45 dB(A): 32% >45 dB(A): 16%
	Sleep interruption	-	-	N=718 <30 dB(A): 21% 30–35 dB(A): 26% 35–40 dB(A): 26% 40–45 dB(A): 26% >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 Economic benefits (no; yes) Age (years) Gender (male; female)	0.99 (0.97, 1.03) **0.52 (0.27, 0.97)** **1.02 (1.01, 1.03)** **1.47 (1.05, 1.06)**[a]
	Interrupted sleep	Sound levels Economic benefits (no; yes) Age (years) Gender (male; female)	1.03 (1.00, 1.07) **0.45 (0.24, 0.84)** 1.00 (0.99, 1.01) 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

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[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 (ρ[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 (ρ=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

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[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 Pedersen and Persson Waye (2004) Sweden 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] Pseudo-R^2=0.13
SWE-05 Pedersen and Persson Waye (2007) Sweden N=720–744	Annoyance (location not specified)	<37.5 dB(A): 3–4% 37.5–40 dB(A): 6% >40 dB(A): 15%
NL-07 Bakker et al. (2012) The Netherlands N=639–678	Annoyance (outdoors)	<30 dB(A): 4/178 (2%) 30–35 dB(A): 16/213 (8%) 35–40 dB(A): 28/159 (18%) 40–45 dB(A): 17/93 (18%) >45 dB(A): 8/65 (12%) Total: 73/708 (10%)
	Annoyance outdoors (no economic benefit)	<30 dB(A): 4/166 (2%) 30–35 dB(A): 16/199 (8%) 35–40 dB(A): 28/140 (20%) 40–45 dB(A): 15/60 (25%) >45 dB(A): 6/28 (21.4%) Total: 69/586 (12%)
	Annoyance indoors (no economic benefit)	<30 dB(A): 2/167 (1.2%) 30–35 dB(A): 8/191 (4.2%) 35–40 dB(A): 12/140 (8.6) 40–45 dB(A): 15/60 (25%) >45 dB(A): 4/21 (19.0%) 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 Pedersen and Persson Waye (2004) Sweden	Sound pressure level (dB(A))	**1.8 (95%CI 1.5, 2.4)** Pseudo-R^2=0.13
	Sound pressure level (dB(A)) Noise sensitivity	**1.9 (95%CI 1.5, 2.4)** **1.9 (95%CI 1.5, 2.4)** Pseudo-R^2=0.18
	Sound pressure level (dB(A)) General attitude (not negative; negative)	**1.9 (95%CI 1.5, 2.4)** **1.7 (95%CI 1.3, 2.3)** Pseudo-R^2=0.20
	Sound pressure level (dB(A)) General attitude (not negative; negative) Noise sensitivity	**1.9 (95%CI 1.5, 2.5)** **1.8 (95%CI 1.3, 24.1)** **1.8 (95%CI 1.2, 2.7)** Pseudo-R^2=0.24
	Sound pressure level (dB(A)) Visual attitude (not negative; negative)	**1.7 (95%CI 1.3, 2.3)** **1.7 (95%CI 1.3, 2.3)** Pseudo-R^2=0.46
	Sound pressure level (dB(A)) Visual attitude (not negative; negative) Noise sensitivity	**1.8 (95%CI 1.3, 2.4)** **4.9 (95%CI 3.1, 7.7)** 1.25 (95%CI 0.8, 2.0) Pseudo-R^2=0.47
	Sound pressure level (dB(A)) Visual attitude (not negative; negative) General attitude (not negative; negative) Noise sensitivity	**1.8 (95%CI 1.3, 2.4)** **5.1 (95%CI 3.1, 8.4)** 0.9 (95%CI 0.6, 1.3) 1.2 (95%CI 0.8, 1.9) Pseudo-R^2=0.47
SWE-05 Pedersen and Persson Waye (2007) 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)) General attitude (not negative; negative)	1.1 (1.00, 1.25) **13.4 (6.03, 29.59)**
	Sound pressure level (dB(A)) Visual attitude (not negative; negative)	**1.1 (1.01, 1.25)** **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)) Noise sensitivity (5-point scale) General attitude (5-point scale) Visual attitude (5-point scale)	**1.1 (1.04, 1.17)** **1.4 (1.08, 1.87)** **1.7 (1.23, 2.39)** **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 Van den Berg et al. (2008) The Netherlands	Age (OR per year)[b] Gender (male; female)[b] Economic benefits (no; yes)[b]	**OR=1.03 (95%CI 1.01, 1.05)** OR=0.93 (95%CI 0.56, 1.53) **OR=0.05 (95%CI 0.01, 0.19)**
NL-07[c] Pedersen et al. (2009) The Netherlands n=639–678	Sound pressure level (dB(A))	**OR 1.14 (95%CI 1.08, 1.20)**
	Economic benefit (no; yes)	**OR 0.06 (95%CI 0.02, 0.23)**
	Visibility (no; yes)	**OR 13.7 (95%CI 3.2, 59.0)**
	Area type (reference: rural)	
	Rural	OR 1.00
	Rural with main road	**OR 0.34 (95%CI 0.17, 0.71)**
	Built-up	**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="2">Key question:
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 <u>distance</u> from wind turbines? <i>[Systematic Review question on distance has been merged here]</i>
C. Might this association be explained by:
i. chance?
ii. bias? or
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="3">1. Evidence-base <i>(Number of studies, level of evidence and risk of bias and confounding in the included studies)</i></td></tr>
<tr><td rowspan="4">7 level IV aetiology studies (cross-sectional studies)</td><td>A</td><td>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>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>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>Level IV studies or level I to III studies/SRs with a high risk of bias and confounding</td></tr>
<tr><td colspan="3">2. Consistency <i>(If only one study was available, rank this component as 'not applicable')</i></td></tr>
<tr><td rowspan="5">No associations between wind turbine exposure and physical or mental health effects were consistently reported in multiple studies.
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>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>Most studies consistent and inconsistency can be explained</td></tr>
<tr><td>C</td><td>Some inconsistency, reflecting genuine uncertainty around question—for one health related effect (quality of life)</td></tr>
<tr><td>D</td><td>Evidence is inconsistent—for all reported health effects</td></tr>
<tr><td>NA</td><td>Not applicable (one study only)</td></tr>
</table>

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)*

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. 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.	A	Very large
	B	Substantial
	[✓ C]	Moderate—for health-related effects (sleep disturbance/sleep quality and quality of life)
	[✓ D]	Slight/restricted—for health effects and a relevant non-health effect (annoyance)

4. Generalisability *(How well does the body of evidence match the population being targeted by the NHMRC advice?)*

Poor response rates. Unknown whether responders are similar to non-responders and thus representative of all residents near wind farms.	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?)*

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.	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)*

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 A C	Evidence is inconsistent—for health effects All studies consistent—for one relevant non-health effect (annoyance) and one health related effect (sleep disturbance/sleep quality) Some inconsistency, reflecting genuine uncertainty around question—for one health related effect (quality of life)
3. Population health impact	D 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 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. 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

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[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

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[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) 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). 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). 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 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. 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. Phase 3: control phase—60 minutes without sound stimulus exposure.	Physiological endpoints: heart and respiratory rates, peripheral temperature and galvanic skin exposure. Subjective assessment of responses (see 'Results' for further details).	Only significant results concerned the subjective mood-based measures, not the objective physiological endpoints. 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≤0.001
Beneficial/harmful	41.02	p≤0.001
Pleasant/unpleasant	8.56	p≤0.001
Acceptable/unacceptable	6.02	p≤0.005
Strong/weak	3.42	p≤0.043
Shrill/soft	5.44	p≤0.008
Arousing/drowsy	10.49	p≤0.001
Exciting/calm	9.41	p≤0.001
Soothing/startling	21.03	p≤0.001
Concentrating/distracting	22.35	p≤0.001
Harmonious/non-harmonious	20.87	p≤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). Noise intensity was 95 dB(A) and 70 dB(A), while the SPL of the infrasound was 95 dB. 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). (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. (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

<table>
<tr><th>Study</th><th>Design</th><th>Exposure</th><th>Outcome</th><th>Limitations</th></tr>
<tr><td colspan="5">(less than 1% difference) in high frequency band of infrasound between pre-exposure and exposure conditions (p<0.05).
Pulse wave: Pulse wave height was statistically significantly reduced upon either exposure compared with pre-exposure (p<0.01).
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.</td></tr>
<tr><td>Waye et al. (2003)</td><td>Cross-over design
Twelve male subjects slept for 5 consecutive nights in a noise-sleep laboratory.
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.</td><td>TN (35 dB LA_{eq}, 50 dB LA_{max}) or LFN (40 dB LA_{eq}).
LFN = frequency range of 31.5–125 Hz.
Third octave band at 50 Hz was amplitude modulated with modulation frequency of 2 Hz.</td><td>Salivary-free cortisol concentration. Subjects also completed questionnaires on mood and sleep quality.</td><td>The authors stated that the study was hypothesis-generating.
The exposure conditions were developed to resemble normal sleeping.
Exposure represents acute exposure (after one night of acclimatisation) and may not be applicable to the wind turbine setting.
There could have been previous exposure and adaptation to TN exposure, whereas the reaction to LFN might have been an alarm reaction.</td></tr>
<tr><td colspan="5">Results
<i>Median values of subjective sleep evaluations</i>
<table>
<tr><th></th><th>Reference night</th><th>TN</th><th>LFN</th></tr>
<tr><td>Response variable[a]</td><td></td><td></td><td></td></tr>
<tr><td>Recalled time to fall asleep (min)</td><td>20</td><td>35</td><td>39[b]</td></tr>
<tr><td>Morning feelings</td><td></td><td></td><td></td></tr>
</table>
</td></tr>
</table>

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

ANOVA for a 3-way interaction between salivary cortisol concentration, noise condition and sensitivity category

F-statistic	p value
3.736[a]	0.06[a]

[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'.

Summary

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. 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 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. [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. 5 subjects in the case series had some form of hearing loss. There was no control group.
Results 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 Only an abstract was available. **Summary** 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 α_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) Mt Lofty Ranges, Australia	Cross-sectional anonymous self-reporting survey. n=93 households Non-standardised survey developed by the authors. Intent of survey not masked from participants.	Households within 10 km of Waterloo Wind Farm, North Mount Lofty Ranges, South Australia. Subgroups within 0–5 km and 5–10 km.	Anyone in the household annoyed by flickering	Confounders Unclear as very little information was reported on participant or household characteristics or pre-existing health conditions. Bias 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). Chance 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

<table>
<tr><td colspan="2">**Key question:**
Is there any reliable evidence of an association between **shadow flicker** 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? *[Systematic Review question on distance has been merged here]*
C. Might this association be explained by:
i. chance?
ii. bias? or
iii. confounding?</td><td>**Morris (2012)**</td></tr>
<tr><td colspan="3">**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">1 level IV study (cross-sectional study) at high risk of bias and confounding</td><td>A</td><td>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>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>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>Level IV studies or level I to III studies/SRs with a high risk of bias and confounding</td></tr>
<tr><td colspan="3">**2. Consistency** *(If only one study was available, rank this component as 'not applicable')*</td></tr>
<tr><td rowspan="5">Only one study</td><td>A</td><td>All studies consistent</td></tr>
<tr><td>B</td><td>Most studies consistent and inconsistency can be explained</td></tr>
<tr><td>C</td><td>Some inconsistency, reflecting genuine uncertainty around question</td></tr>
<tr><td>D</td><td>Evidence is inconsistent</td></tr>
<tr><td>NA</td><td>Not applicable (one study only)</td></tr>
<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="2">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</td><td>A</td><td>Very large</td></tr>
<tr><td>B</td><td>Substantial</td></tr>
</table>

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)

<table>
<tr><td><i>3.</i> Population health impact</td><td>D
/
C</td><td colspan="2">Unknown—for health effects
Moderate— for other relevant non-health effect (annoyance)</td></tr>
<tr><td>4. Generalisability</td><td>C</td><td colspan="2">Evidence not directly generalisable to the target population but could be sensibly applied</td></tr>
<tr><td>5. Applicability</td><td>A</td><td colspan="2">Evidence directly applicable to Australian exposure setting</td></tr>
<tr><td colspan="3"><i>Evidence statement</i>
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.</td><td><i>Evidence rating</i>
D</td></tr>
</table>

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) German government-sponsored study	RCT 2 groups of males and females: Group 1, 32 students (mean age = 23 years); Group 2, 25 professionals (mean age = 47 years) Each group randomly assigned to either 60 minutes of simulated flicker (experimental group) or similar lighting conditions without periodic shadow or flicker. 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 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				

Study	Design	Exposure	Outcomes	Limitations
German. **Summary** 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)'.				
Shirakawa et al. (2001)	Non-randomised provocation study comparing multiple groups with varying levels of colour flicker at varying frequencies. All subjects were photosensitive (n=35).	Rates of photoparoxysmal response (PPR) provocation.		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. 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. Potential for observer bias given the lack of concealment of allocation.
Results *Proportions of individuals experiencing PPR provocation at 3, 10, 20 and 30 Hz among the 35 subjects*				

	Frequency			
	3 Hz	10 Hz	20 Hz	30 Hz
Subjects with PPR provocation, %	5.7	28.6	22.9	28.6

Summary

The PPR provocation rates at 10, 20, and 30 Hz were significantly greater than at 3 Hz (p<0.01 for all comparisons).

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.

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[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

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[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.

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[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. 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. 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]

Study	Design	Exposure	Outcomes	Limitations
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. p values: [a] <0.05; [b] <0.01; [c] <0.001. 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). **Summary** 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.				
Johansen (2000)†	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.	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. 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).	Diseases of the CNS—dementia, demyelinating diseases, cerebral palsy, epilepsy, motor neuron diseases and spinal medullary disease.	Limitations include retrospective design of the study, potential for misclassification of exposure and non-randomised nature of the comparison.
Results				

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]

<table>
<tr><th>Study</th><th>Design</th><th>Exposure</th><th>Outcomes</th><th>Limitations</th></tr>
<tr><td colspan="5">
<table>
<tr><td>Cerebral palsy</td><td>45</td><td>1.00</td><td>0.50</td><td>[0.16,1.54]</td><td>0.88</td><td>[0.33,2.39]</td><td>0.78</td><td>[0.25,2.42]</td><td>2.57</td><td>[0.92,7.19]</td></tr>
<tr><td>Epilepsy</td><td>148</td><td>1.00</td><td>1.51</td><td>[0.78,2.95]</td><td>1.50</td><td>[0.77,2.94]</td><td>2.03</td><td>[1.02,4.05]</td><td>1.61</td><td>[0.79,3.29]</td></tr>
<tr><td>Motor neuron disease</td><td>20</td><td>1.00</td><td>0.86</td><td>[0.16,4.71]</td><td>1.27</td><td>[0.26,6.32]</td><td>1.56</td><td>[0.29,8.53]</td><td>1.90</td><td>[0.33,11.13]</td></tr>
<tr><td>Spinal medullary disease</td><td>13</td><td>1.00</td><td>1.35</td><td>[0.14,13.04]</td><td>1.35</td><td>[0.14,12.97]</td><td>0.81</td><td>[0.05,12.96]</td><td>3.96</td><td>[0.43,36.59]</td></tr>
</table>
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.
</td></tr>
<tr><td>Johansen, Feychting et al. (2002)†</td><td>Retrospective cohort study. Investigators attempted to examine concerns about potential cardiovascular effects of occupational exposure to ELF.
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.</td><td>Exposure to ELF in the 50–60 Hz frequency band.
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.
These were also categorised into ELF (background exposure (≤0.09 µT), medium exposure (0.1–0.99 µT), and high exposure (≥1.0 µT)).</td><td>Incidence ratios for pacemaker implantation.</td><td>Awareness of exposure and observer bias in level or intensity of determining the outcome from registers.
The study addresses only those heart diseases that require implantation of a pacemaker.
Assessment of exposure was not obtained from individual data.
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.</td></tr>
</table>

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. 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. 18 studies included on ELF and childhood cancer—17 case-control studies (2 nested) and one cohort study. 7 studies included on ELF and amyotrophic lateral sclerosis (ALS)—5 case-control and 2 cohort studies. 5 studies included on ELF and Alzheimer's disease—4 case-control studies and one cohort study. 5 studies on ELF and suicide—2 case-controls and 3 studies calculated the standardised or proportional mortality ratio. 6 studies on ELF and depression—5 cross-sectional and one case-control study. 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. 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 *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

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[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.

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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

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[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

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[46] The IEA *Dictionary of Epidemiology* (2008) states 'possibility' rather than 'probability'; however, for the purposes of the current report we prefer 'probability'.

	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.

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

	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.* 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.* 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).

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. 2. The WHO Expert Committee on Health Statistics noted in its sixth report (1959) that morbidity could be measured in terms of three units: a. persons who were ill b. the illnesses (periods or spells of illness) that these persons experienced c. the duration (days, weeks etc.) of these illnesses.

<table>
<tr><td>Mortality</td><td>Death</td></tr>
<tr><td>Nocebo effect</td><td>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.</td></tr>
<tr><td>Noise</td><td>Unwanted sound or an unwanted combination of sounds.</td></tr>
<tr><td>Narrative review</td><td>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.</td></tr>
<tr><td>Odds ratio (OR)*</td><td>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:
<table>
<tr><td></td><td>Exposed</td><td>Unexposed</td></tr>
<tr><td>Disease</td><td>a</td><td>b</td></tr>
<tr><td>No disease</td><td>c</td><td>d</td></tr>
</table>
The odds ratio (cross-product ratio) is ad/bc.</td></tr>
<tr><td>Parallel evidence (indirect evidence)</td><td>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).</td></tr>
<tr><td>Participants/responders</td><td>Those who have participated in a trial or study, or have responded to a survey questionnaire or interview.</td></tr>
<tr><td>Pearling</td><td>The process of checking the reference lists of articles included in a systematic review for more articles that are potentially relevant.</td></tr>
<tr><td>Pearson’s correlation coefficient (r)</td><td>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.</td></tr>
<tr><td>Peer-reviewed literature</td><td>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.</td></tr>
<tr><td>Photoparoxysmal response</td><td>A physiological reaction to intermittent photic stimulation or other visual stimuli of daily life; detected and measured with electroencephalography (EEG).</td></tr>
</table>

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'.

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. 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

	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). 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. 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). 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

	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).
	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

(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 ($20x10^{-6}$ 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*. 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: A-weighting: the most common scale for assessing environmental and occupational sound. The result is a level measured in dB(A). 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).

	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

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

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, α_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”) 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*") 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*") Limits: English language, published 2011 - 2012
EPPI Centre (papers on public policy) Evidence library Bibliomap database DoPHER database TroPHI database	http://eppi.ioe.ac.uk/cms/	“wind” (free text search)
Scirus (documents from science/scientist webpages) 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

		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” “wind power” “wind tower” “wind turbine” “wind technology” “wind energy” “wind” AND “renewable energy” “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) 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) The first 50 citations will be assessed
MedNar 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) Pedersen et al. (2009) 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) Pedersen (2011)
SWE-05	Pedersen and Persson Waye (2007)	Sweden	Pedersen and Larsman (2008) 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>.

ARTICLE DETAILS

Reference [1]

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.

Affiliation/source of funds [2]

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.

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.

Study design [3]	Level of evidence [4]	Location/setting [5]
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.	IV	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. **Proximity/distance:** 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: 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. **Specific exposure details:** 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).	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'). **Sample size [9]** See 'Population characteristics'. Survey sample selected from addresses provided by Land Registry Office – for each subgroup either a random sample was selected or all addresses that

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

<table>
<tr><td></td><td>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’).</td></tr>
<tr><td>INTERNAL VALIDITY
Confounding subscale [13]
<i>Comment on sources of confounding:</i>
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.
Bias subscale [14]
<i>Comment on sources of bias:</i>
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.</td><td>EXTERNAL VALIDITY
Generalisability [15]
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.
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.</td></tr>
<tr><td colspan="2">Reporting subscale [17]
<i>Comment on quality of reporting:</i>
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.</td></tr>
<tr><td colspan="2">Chance [18]
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</td></tr>
</table>

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

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].	NA	See [20].	See [20].

Public health importance (1–4) [26]	Relevance (1–5) [27]
Unable to determine according to NHMRC ranking criteria.	5

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. 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]

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]

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.

Funded through the European Union as a Specific Support Action, Contract No. 0044628.

Study design [3]	Level of evidence [4]	Location/setting [5]
Cross-sectional study.	IV	Areas in The Netherlands with ≥2 wind turbines of power ≥500 kW. **Proximity/distance:** 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: ≥2 wind turbines of power ≥500 kW. **Specific exposure details:** 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	No non-exposed groups were included in the study. A distribution of participant characteristics (incomplete) across different sound level exposures was included (see 'Specific exposure details'). **Sample size [9]**

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]

Respondents, n=725; non-respondents, n=1223; response rate 37%.

See 'Population characteristics'.

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]

NA (cross-sectional study)

Outcome(s) measured and/or analyses undertaken [12]

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.

Outcomes measured were:

Response (do not notice / annoyance) to wind turbine noise outdoors and indoors, and attitude to wind turbines.

INTERNAL VALIDITY

Confounding subscale [13]

Comment on sources of confounding:
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

Generalisability [15]

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]** **95% CI [25]**	**Harms (NNH) [24]** **95% CI [25]**
See 'Adverse effect outcomes' [20].	NA	See 'Adverse effect outcomes' [20].	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]

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]

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.

Funded by the European Union.

Study design [3]

Cross-sectional study.

Level of evidence [4]

IV

Location/setting [5]

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.

Proximity/distance:
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]

Wind farm details:
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.

Specific exposure details:
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).

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

Control(s) description [8]

No non-exposed groups were included in the study.

A distribution of different sound level exposures was included (see 'Specific exposure details' and 'Population characteristics').

Sample size [9]

See 'Population characteristics'.

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.

INTERNAL VALIDITY

Confounding subscale [13]

Comment on sources of confounding:
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.

Bias subscale [14]

Comment on sources of bias:
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.

EXTERNAL VALIDITY

Generalisability [15]

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.

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:
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.

Chance [18]

Statistical adjustments for undertaking multiple statistical tests were not reported.

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 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).

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]

See 'Adverse effect outcomes' [20].

Control group [22]

NA

Measure of effect / effect size [23]

95% CI [25]

See [20].

Harms (NNH) [24]

95% CI [25]

See [20].

Public health importance (1–4) [26]

Ranked 3 for overall chronic disease outcome. Ranked 3 or 4 for health outcomes taken singly.

Relevance (1–5) [27]

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.

ARTICLE DETAILS

Reference [1]

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.

Affiliation/source of funds [2]

Killaloe, Flesherton, University of Waterloo, Waterloo and Intelligent Health Solutions, Fergus, Ontario, Canada.

Study design [3]	**Level of evidence [4]**	**Location/setting [5]**
Cross-sectional study	IV	Residents in five project areas in Ontario, Canada, where adverse health effects had been anecdotally reported: 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). **Proximity/distance:** 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.

Exposure description [6]

Wind farm details sourced from:
<http://en.wikipedia.org/wiki/List_of_wind_farms_in_Canada>

Melancthon Phase 1 and 2 (Amaranth), commenced operation in March 2006
133 General Electric SLE 1.5-MW turbines, sited in a farming community
Turbine height = 80 m
Rotor diameter = 77 m

Kingsbridge 1 Wind Power (Goderich), commenced

Control(s) description [8]

No non-exposed groups were included in the study.

Sample size [9]

See 'Population characteristics'.

operation in March 2006 22 Vestas V80 1.8-MW turbines, sited on the southeast shore of Lake Huron Turbine height = 78 m Rotor diameter = 80 m *Kruger Energy Port Alma (Port Alma),* commenced operation in November 2008 44 Siemens 2.3-MW Mark II turbines, sited on the north shore of Lake Erie Turbine height = 80 m Rotor diameter = 82.5 m *Ripley Wind Power (Ripley),* commenced operation in December 2007 38 Enercon E-82 2.0-MW turbines, sited along the shore of Lake Huron Turbine height = 79 m Rotor diameter = 82 m *Enbridge Ontario Wind Farm (Kincardine),* commenced operation in August 2008 110 Vestas V82 1.65-MW turbines, sited along the shore of Lake Huron Turbine height = 80 m Rotor diameter = 82 m *Erie Shores Wind Farm (Port Burwell),* commenced operation in April 2006 66 General Electric SLE 1.5-MW turbines, sited along the shore of Lake Erie Turbine height = 80 m Rotor diameter = 77 m **Specific exposure details:** Not reported. **Sample size [7]** 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. 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). Respondents were divided into subgroups according to distance from nearest wind turbine: 24% adults living mean 428 m (range 350–490 m) from nearest wind turbine 23% adults living mean 587 m (range 500–67 m) from	

<table>
<tr><td>nearest wind turbine
30% adults living mean 769 m (range 700–808 m) from nearest wind turbine
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]**
Exposure group:
n=103 respondents; mean age = 52 years (range 18–83); female = 52%.
Control group(s):
None.</td></tr>
<tr><td>**Length of follow-up [11]**
NA (cross-sectional study).
Length of exposure:
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]**
Health outcomes measured by self-reporting survey.</td></tr>
<tr><td>**INTERNAL VALIDITY**
Confounding subscale [13]
Comment on sources of confounding:
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.
Bias subscale [14]
Comment on sources of bias:
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**
Generalisability [15]
Potential for differences between the total population living near the included wind farms and those that participated in the survey.
Applicability [16]
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]**
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]**
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] 95% CI [25]	NC
	Mean distance from turbine:						
	Subgroups:				Total:	p (Fisher's exact)	
	428 m	587 m	769 m	1154 m	707 m		
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 decreased 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.

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. **Proximity/distance:** 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.

Length of follow-up [11]

NA

Length of exposure:
Wind farm commenced operation in October 2010. Survey conducted in April 2012.

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).

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.

EXTERNAL VALIDITY

Generalisability [15]

Survey distributed to all households within proximity of a wind farm / wind turbines.

Applicability [16]

Survey conducted in Australia.

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.

Chance [18]

No data analysis.

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).

<table>
<tr><td colspan="5">RESULTS</td></tr>
<tr><td>Adverse effect outcomes [20]</td><td>Exposure group [21]</td><td>Subgroup [22]</td><td>Measure of effect / effect size [23]
95% CI [25]</td><td>Harms (NNH) [24]
95% CI [25]</td></tr>
<tr><td>Distance from turbine:</td><td>0–10 km (all responders)</td><td>0–5 km (subgroup)</td><td>NC</td><td>NC</td></tr>
<tr><td>Disturbed sleep</td><td>27/93 (29%)</td><td>16/41 (39%)</td><td></td><td></td></tr>
<tr><td>Seriously affected</td><td>7/44 (16%)</td><td>6/25 (24%)</td><td></td><td></td></tr>
<tr><td>Moderately affected</td><td>17/44 (39%)</td><td>10/25 (40%)</td><td></td><td></td></tr>
<tr><td></td><td colspan="2">Public health importance (1–4) [26]
Not able to determine from the NHMRC criteria.</td><td colspan="2">Relevance (1–5) [27]
5</td></tr>
<tr><td colspan="5">Comments [28]
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.</td></tr>
</table>

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]

Cross-sectional study.

Level of evidence [4]

IV

Location/setting [5]

Residences of Mars Hill and Vinalhaven, Maine, USA.

Proximity/distance:
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:

	Mars Hill	*Vinalhaven*
Distance from turbine	Measured noise $LA_{eq, 1\ hour}$ (range)	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.

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.

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.

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.

Chance [18]

The possibility of spurious significant associations arising by chance cannot be excluded as multiple statistical tests were conducted.

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.

RESULTS	**Harms (NNH) [24] 95% CI** See [20].

Adverse effect outcomes [20]	**Exposure group [21] (near)** **Mean distance from turbine:**			**Control group [22] (far)** **Mean distance from turbine:**			**Measure of effect / effect size [23] 95% CI [25]**
	Subgroups:		**Total:**	**Subgroups:**		**Total:**	**Results for total group differences**
	601 m	**964 m**	**792 m**	**4181 m**	**5800 m**	**5248 m**	
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) 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) 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) 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) p = 0.47
n (%) new diagnosis of insomnia			2/38 (5.3%)			0/41 (0%)	RR not calculable p = 0.23
n (%) new diagnosis of depression or anxiety			9/38 (23.7%)			0/41 (0%)	RR not calculable 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) 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 p <0.0001

[a] Mental component score

[b] Physical component score

Public health importance (1–4) [26]		**Relevance (1–5) [27]**
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.

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. **Proximity/distance:** 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: 66 turbines (Siemens SWT-2.3-82 VS) Turbine height = 125 m Rotor diameter = 82 m **Specific exposure details:** Typical noise exposure range = 24–54 dB(A). **Sample size [7]** 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). **Sample size [9]** ≈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 Psychological QoL: rank of 4 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]

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]

Department of Environmental Medicine, Göteborg University, Göteborg, Sweden.

Funded through grant P13644-1 from the Swedish Energy Agency and Adlerberska Research Foundation.

Study design [3]	**Level of evidence [4]**	**Location/setting [5]**
Cross-sectional study	IV	Five areas within a 22-km^2 region of southern Sweden. Landscape predominantly flat and mainly agricultural, but with small industries, roads and railroads present. **Proximity/distance:** Distance from dwelling of respondent to nearest turbine, range = 150–1199 m

Exposure description [6]

Wind farm details:
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.

Specific exposure details:
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).

Sample size [7]

Total = 513; respondents, n=351; non-respondents, n=162; response rate 68%.

Control(s) description [8]

No non-exposed groups were included in the study. Responder characteristics across different types of environmental exposure were reported (see 'Specific exposure details').

Sample size [9]

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.

Bias subscale [14]

Comment on sources of bias:
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 n=12	30.0–32.5 n=70	32.5–35.0 n=132	35.0–37.5 n=62	37.5–40.0 n=40	>40.0 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>Exposure group [21]
See ‘Adverse effect outcomes’ [20].</td>
<td>Control group [22]
NA</td>
<td>Measure of effect / effect size [23]
95% CI [25]
See [20].</td>
<td>Harms (NNH) [24]
95% CI [25]
NR—health outcomes not reported.</td>
</tr>
<tr>
<td colspan="2">Public health importance (1–4) [26]
Unable to determine according to NHMRC ranking criteria.</td>
<td colspan="2">Relevance (1–5) [27]
5</td>
</tr>
<tr>
<td colspan="4">Comments [28]
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>

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. **Proximity/distance:** 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

Confounding subscale [13]

Comment on sources of confounding:
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.

Bias subscale [14]

Comment on sources of bias:
Study intent was masked, but unclear how effectively and so whether recall bias has affected results.

EXTERNAL VALIDITY

Generalisability [15]

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).

Applicability [16]

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 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	
	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.

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]	**Outcome(s) measured and/or analyses undertaken [12]**
NA (cross-sectional study).	Three constructs of annoyance (due to noise, visual

	attitude and general attitude). No health outcomes measured.
INTERNAL VALIDITY **Confounding subscale [13]** ***Comment on sources of confounding:*** Confounding is a risk as the possibility of different distributions of economic benefit among the sound exposure groups was not analysed. **Bias subscale [14]** ***Comment on sources of bias:*** Recall bias cannot be excluded, although masking of study intent was attempted in both studies.	**EXTERNAL VALIDITY** **Generalisability [15]** 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. **Applicability [16]** 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]
See ‘Adverse effect outcomes [20].</td>
<td>Control group [22]
NA</td>
<td>Measure of effect / effect size [23]
95% CI [25]
See [20].</td>
<td>Harms (NNH) [24]
95% CI [25]
Health effects not reported.</td>
</tr>
<tr>
<td colspan="2">Public health importance (1–4) [26]
Cannot be determined according to NHMRC ranking criteria.</td>
<td colspan="2">Relevance (1–5) [27]
5</td>
</tr>
<tr>
<td colspan="4">Comments [28]
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] NA (cross-sectional study)	**Outcome(s) measured and/or analyses undertaken [12]** (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; (b) association between annoyance outdoors due to wind turbine noise and the self-reported health symptoms listed at (a); (c) association between annoyance indoors due to wind turbine noise and self-reported health symptoms listed at (a).
INTERNAL VALIDITY **Confounding subscale [13]** ***Comment on sources of confounding:*** 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. **Bias subscale [14]** ***Comment on sources of bias:*** 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** **Generalisability [15]** 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 Sweden and The Netherlands are comparable to those living near wind farms in Australia.
Reporting subscale [17] ***Comment on quality of reporting:*** 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]	SWE-05[a]	NL-07[b]
	n=319–333[c]	n=720–744[c]	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]	SWE-05[a]	NL-07[b]
	n=319–333[c]	n=720–744[c]	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]	SWE-05[a]	NL-07[b]
	n=318–331[c]	n=719–743[c]	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]** **95% CI [25]**	**Harms (NNH) [24]** **95% CI [25]**
See ‘Adverse effect outcomes’ [20].	NA	See [20].	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.

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Study outcome(s) unsuitable

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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.

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Study exposure unsuitable

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Study not in English language

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Study comparator unsuitable

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Article is not a study (commentary/opinion)

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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

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

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

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

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

				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

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

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

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

		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 By Parkesbourne/Mummel Landscape Guardians Inc.	Guidelines/regulations on wind farm planning; exclude

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

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

			Australia	
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—

		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

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

		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

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

		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

			2009	
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

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;

				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;

				exclude
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

			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

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

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

		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

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

		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

		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

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

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

			September 2010	
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

The Director General

Maisons-Alfort, 14 February 2017

OPINION
of the French Agency for Food, Environmental and Occupational Health & Safety

regarding the expert appraisal on the "Assessment of the health effects of low-frequency sounds and infrasounds from wind farms"

ANSES undertakes independent and pluralistic scientific expert assessments.
ANSES primarily ensures environmental, occupational and food safety as well as assessing the potential health risks they may entail.
It also contributes to the protection of the health and welfare of animals, the protection of plant health and the evaluation of the nutritional characteristics of food.

It provides the competent authorities with all necessary information concerning these risks as well as the requisite expertise and scientific and technical support for drafting legislative and statutory provisions and implementing risk management strategies (Article L.1313-1 of the French Public Health Code).

Its opinions are published on its website.
This opinion is a translation of the original French version. In the event of any discrepancy or ambiguity the French language text dated 14 February 2017 shall prevail.

On 4 July 2013, ANSES received a formal request from the Directorate General for Risk Prevention (DGPR) and the Directorate General for Health (DGS) to undertake the following expert appraisal: assessment of the health effects of low-frequency sounds and infrasounds from wind farms.

1. BACKGROUND AND PURPOSE OF THE REQUEST

The development of wind turbines as renewable sources of electrical energy has led to questions about their potential to produce low-frequency sounds (20 Hz to 200 Hz) and infrasounds (below 20 Hz), and their possible impact on health.

In March 2006, the French National Academy of Medicine considered, in a report on the impact of the operation of wind turbines on human health, that the noise impact of wind farms is comparable to that of airports, transport infrastructure and factories. This report recommended classifying wind farms as "industrial zones" and keeping a minimum distance of 1,500 metres between wind turbines and residential areas.

Further to a new request from the DGPR and DGS, the French Agency for Environmental Health (AFSSE) concluded, in its report entitled "Health effects of noise from wind turbines" published in March 2008, that the noise emissions of wind turbines have no direct consequences on health, whether in terms of the auditory system or effects related to exposure to low frequencies and infrasounds. This report also considered that setting a systematic minimum distance of 1,500 metres, without taking into account the environment (topographic in particular) of the wind farm, did not seem appropriate.

The French regulations on wind turbines have since been amended, with the introduction of a minimum separation distance of 500 metres from any residential dwelling, and then the classification of wind farms in the regime of Classified Installations for the Protection of the Environment (ICPE, Ministerial Orders of 26 August 2011). These texts consider the octave bands from 125 to 4,000 Hz. Very low frequencies and infrasounds, which are more difficult to measure, are currently not taken into account.

As highlighted in a review of the French and foreign regulations produced in 2014 by the French Information and Documentation Centre on Noise (CIDB), at ANSES's request, there are currently no harmonised regulations in the European Union specific to noise from wind turbines or to infrasounds and low-frequencies from all other noise sources. Only a few national guidelines include specific provisions on wind farms. Most of the complaints filed about low-frequency noises have been related to situations of exposure inside buildings. Some countries[1] have therefore formulated recommendations on exposure to low-frequency noises and infrasounds inside homes, most often located near industrial facilities.

In France, complaints from local residents regarding noise from wind turbines have been reported to the DGPR by Regional Directorates of the Environment, Land-Use Planning and Housing (DREALs).

In this context, on 4 July 2013, the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) received a formal request from the Directorate General for Risk Prevention (DGPR) and the Directorate General for Health (DGS) to assess the health effects of low-frequencies and infrasounds from wind farms. The Agency was asked to address the following points in particular:

- conduct a review of the available knowledge of the auditory and extra-auditory health effects of wind farms, in particular in the area of low-frequencies and infrasounds;
- study the regulations implemented in countries, mainly European, faced with the same issues;
- measure the noise impact of wind farms, especially of those where disturbance has been reported by local residents, taking into account the contributions of low-frequencies and infrasounds;
- propose avenues of improvement taking into account possible health effects in the regulations, as well as recommendations to better understand these health effects in impact assessments for wind turbine projects.

2. EXPERT APPRAISAL METHOD

Organisation of the expert appraisal

ANSES entrusted the examination of this formal request to the Working Group on the "Health effects of low frequencies and infrasounds from wind farms", reporting to the Expert Committee (CES) on the "Assessment of risks related to physical agents, new technologies and development areas".

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[1] For example, Denmark officially included low-frequency sound in its regulations on the noise impact of wind farms. But the insulation values used to calculate levels of exposure to low-frequency sounds in homes are controversial.

This Working Group, set up following a public call for applications, brought together experts selected for their competence and independence in complementary scientific and technical fields. It held 27 plenary meetings (at ANSES) between April 2013 and October 2016.

Several hearings with stakeholders and eminent scientists were held during these meetings, to enable the Working Group to have all useful and necessary information to undertake the expert appraisal.

Lastly, two additional studies were requested, as part of the research and development agreements financed by ANSES:

- a review, by the CIDB, of the current regulations on low-frequency noise, applying to wind turbines in France and abroad;
- an analysis of the socio-economic context surrounding the construction of wind farms, by the International Environment and Development Research Centre (CIRED)[2].

The methodological and scientific aspects of this expert appraisal work were regularly submitted to the CES. The produced report and collective expert appraisal summary take into account the comments and additional information provided by the members of the CES.

The expert appraisal was carried out in accordance with French Standard NF X 50-110 "Quality in Expert Appraisals – General Requirements of Competence for Expert Appraisals".

ANSES analyses interests declared by experts before they are appointed and throughout their work in order to prevent risks of conflicts of interest in relation to the points addressed in expert appraisals.

The experts' declarations of interests are made public *via* the ANSES website (www.anses.fr).

Description of the expert appraisal method

■ Measurement campaigns on exposure to noise from wind turbines

In order to supplement the data from the scientific literature on exposure to infrasounds and low frequencies from wind farms, ANSES commissioned noise measurement campaigns (including low frequencies and infrasounds) in the vicinity of several wind farms. These acoustic measurements were taken by the National Centre for Studies and Expertise on Risks, Environment, Mobility, and Urban and Country planning (CEREMA[3]).

For the selection of sites (wind farms) for the measurement campaigns, a compromise was made between the number of sites to be included in the study and the desired level of analysis for each of these sites.

The measurement campaign protocol was designed so as to have, for each studied wind farm:

- all possible classes of wind (wind speed and direction categories);
- access to four simultaneous measurement points:
    - o at the regulatory minimum separation distance (500 m);

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[2] Joint research unit no. 8568 of the French National Centre for Scientific Research (CNRS).

[3] CEREMA is a public agency created in 2014 to provide enhanced scientific and technical support for the development, implementation and evaluation of public policies for development and land planning. It comprises the eight former Technical Centres for Public Works (CETEs), the former Centre for Studies on Networks, Transport, Urban Planning and Public Construction (CERTU), the former Centre for Technical Maritime and River Studies (CETMEF), and the former Technical Agency for Transport, Roads and Planning (SETRA).

  - at the façade and inside a home (preferably as close as possible to a wind turbine);
  - and close to the source, in order to characterise the noise emissions of wind turbines.

Following an analysis comparing several criteria of interest listed by the Working Group's experts and the known characteristics of wind farms in France, three sites were selected, with the following characteristics:

- site 1: farm with the largest (blade diameter) and most powerful wind turbines in operation in France on the dates of this analysis period. These wind turbines are theoretically those emitting the most infrasounds and low frequencies, due to their large dimensions, and prefigure future wind turbines of over 3 MW (measurement period: from 12/10/2015 to 19/10/2015; 1,000 usable 10-minute samples);
- site 2: farm with a "conventional" configuration against which complaints had been filed (measurement period: from 30/06/2015 to 06/07/2015; 887 usable 10-minute samples);
- site 3: farm with a "conventional" configuration against which no complaints had been filed (measurement period: from 23/03/2015 to 27/03/2015; 541 usable 10-minute samples).

■ Review of knowledge related to the health effects of infrasounds and low-frequency noise emitted by wind farms

A systematic literature search[4] by keywords was undertaken for the period up to 1 December 2015; the corpus of documents was regularly updated during the expert appraisal.

In addition to this search, other documents were found *via* the references in the key reports and documents previously identified.

Lastly, the body of literature was supplement *via* hearings[5], in which the various invited stakeholders informed the Working Group of the references they considered relevant on the topic.

These various documents were sorted, analysed and summarised.

Given the controversies associated with "environmental diseases" such as vibroacoustic disease (VAD) and wind turbine syndrome (WTS), the analyses of articles relating to them were compiled in a specific summary.

Moreover, the analyses of articles were grouped together by study type:

- experimental data;
- epidemiological data.

■ Assessment of health risks related to exposure to infrasounds and low-frequency sounds emitted by wind farms

The conclusions of the expert appraisal thus rely on a comparison of data on exposure to the infrasounds and low frequencies measured near wind farms, and the levels of evidence provided by the review of knowledge on the potential health effects related to exposure to infrasounds and low-frequency sounds.

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[4] The following search engines were used: PubMed, Science Direct and Google Scholar.

[5] In particular the French Renewable Energies Union (SER), Électricité de France (EdF) / Électricité de France – Énergies Nouvelles, France Énergie Éolienne (FEE), Vent de Colère, the Sustainable Environment Federation (FED) and several residents living near wind farms.

3. ANALYSIS AND CONCLUSIONS OF THE CES

Results and conclusions of the collective expert appraisal

The CES on "Physical agents, new technologies and development areas" adopted the collective expert appraisal work and its conclusions and recommendations as described in this summary at its meeting of 5 December 2016 and informed the ANSES General Directorate accordingly.

■ Exposure of local residents to infrasounds and low frequencies emitted by wind turbines

The measurement of exposure to infrasounds and low frequencies in residents living near wind farms involves several complexities:

- of a metrological nature: the calibration of measurement instruments is complicated and unsatisfactory for very low frequencies, as instrumental background noise is higher at low frequencies;
- of an organisational nature: the current lack of published technical standards limits the relevance of comparisons between measurements taken by various teams, and does not guarantee the quality of practices. For example, the choice of the apparatus used and frequency bands studied heavily influences the results. However, a draft standard on the measurement of infrasounds for all noise sources is about to be published by AFNOR;
- related to the particularities of the noise source and its environment: the sound signal fluctuates over time depending on various factors, some of which are clearly identified (wind speed, topography, etc.) while others remain undetermined or cannot be verified (wind turbulence on the blades or in the propagation medium, local temperature gradients, etc.);

Inside homes, there are also difficulties measuring weak signals, and problems of sound wave reverberation.

These metrological challenges were taken into account in the measurement campaign undertaken near the three wind farms. This work, supplemented by the data from the literature, led to the following findings:

- wind turbines are sources of noise whose spectrum of sound emission mainly contains infrasounds and low-frequency sounds. According to the scientific literature, the sound level of these spectral components increases with the size of the wind turbine's rotor;
- the measurement results on the noise emissions of the wind turbines confirmed the trends described in the scientific literature:
  - o the general profile of the spectrum of noise emissions from wind farms (near-linear decrease in the sound level with the logarithm of the frequency) was found on all the sites, with few major differences. A few frequency peaks, probably attributable to mechanical noise in the nacelle, were found in the infrasound and low-frequency part of the spectrum;
  - o the greater the increase in wind speed, the greater the increase in noise emissions of infrasounds and low frequencies, up to a theoretical maximum;

- the measurement results for sound levels at 500 m and 900 m (at the façades of homes) from the wind farms confirmed the trends observed in the scientific literature for two of the three explored sites[6]:
    - a wide spread of measurements as a function of time for a given wind farm and wind conditions. Other factors that are difficult to verify (occasional wind turbulence, contamination by other noise sources, etc.) may have had a non-negligible impact on measured noise;
    - the hearing thresholds for infrasounds and low frequencies (< 50 Hz) were not exceeded;
- the infrasound and low-frequency signals measured inside homes, in conditions where wind turbines were operating with the highest wind speeds (above 6 m/s) encountered when taking the measurements, were below the hearing threshold (ISO 226[7]).

The CES points out that noise level measurements expressed in dBA, which are those recommended by the technical standards, are not suited to infrasounds or low-frequency sounds. However, the particular profile of the spectrum of wind turbine noise implies proportionality between the spectral content measured in dBA and the spectral content of infrasounds and low-frequency sounds. Thus, relevant information regarding exposure to infrasounds and low frequencies can be obtained from exposure data measured in dBA. This finding is consistent with those established in recent studies.

Therefore, in light of the emission spectra of current wind turbines, limiting a noise level in dBA also means limiting the noise level of infrasounds and low frequencies.

■ Health effects of infrasounds and low-frequency sounds: exploitation of the available scientific knowledge

An imbalance between primary and secondary sources

An examination of the available data on the health effects of infrasounds shows a strong imbalance between primary (documents on original experiments or scientific studies) and secondary (reviews of the scientific literature and opinion articles) literature sources. Indeed, there are many secondary sources while the number of primary sources they are supposed to summarise is limited. This particularity, combined with the markedly different conclusions of these reviews, clearly shows that there is strong public controversy surrounding this issue.

Review of the health concerns expressed by residents living near wind farms

The symptoms described by some residents living near wind farms, which they associate with their exposure to noise emissions from wind turbines, are extremely varied. In the literature, they were classified into two categories:

- those associated with vibroacoustic disease (VAD);
- those characteristic of wind turbine syndrome (WTS).

VAD was defined by a single research team[8] and refers to a specific biological mechanism that it links to exposure to infrasounds and low-frequency sounds (growth of collagen and elastin fibres in extracellular matrices, in the absence of any inflammatory process). This mechanism could,

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[6] The sound contribution of wind turbines in relation to other noises recorded for local residents at site no. 2 could not be clearly established, causing this site to be excluded from the analyses.

[7] ISO 226:2003: Acoustics - Normal equal-loudness-level contours.

[8] Research team of Alves-Pereira and Castelo-Branco.

according to these authors, ultimately lead to the occurrence of a wide variety of health effects (fibroses, damage to the immune system, respiratory effects, genotoxic effects, morphological changes in organs, etc.).

The Working Group attributed a very low level of evidence to this assumption of a mechanism for health effects, due to its weak scientific bases and major biases in the studies published by this team, often in non-peer-reviewed journals, whose results have not been reproduced by other research teams. Therefore, the Working Group did not take VAD into account in the assessment of the potential health risks related to noise emissions from wind turbines.

Wind turbine syndrome was described in the literature (Pierpont 2009) as a set of symptoms reported by residents living near wind farms which they themselves attribute to wind turbines. These symptoms (sleep disturbance, headaches, tinnitus, balance problems, etc.) are not specific to a disease. They are found in syndromes of idiopathic environmental intolerance in particular. However, they correspond to a set of signs that may occur further to stress or sleep loss, which may become disabling for the subject who experiences them.

Review of the experimental data

- ✓ **Potential mechanisms for effects via the cochleovestibular system, which have yet to be confirmed**

Recently acquired knowledge related to the physiology of the cochleovestibular system has highlighted several potential mechanisms for physiological effects that could be activated in response to exposure to infrasounds and low-frequency sounds. This sensory system is indeed particularly susceptible to these frequencies, more so than other parts of the human body.

The current data suggest that sound frequencies that are too low or levels that are too soft to be clearly heard could have effects mediated by receptors of the cochleovestibular system. The possible mechanisms include the following:

- the induction of non-auditory responses by the vestibular cells when a very low-frequency sound reaches the base of the cochlea;
- the "non-conventional" stimulation of the most apical auditory sensory cells activating non-auditory cochlear pathways;
- the induction of ionic and volume imbalances in the fluid of the inner ear, through the prolonged overall generation of vibrations of the basilar membrane by a very low-frequency sound;
- the induction of modulations in the response of auditory sensory cells to ordinary sounds by very low-frequency sounds, which themselves are inaudible but affect the audibility of concomitant audible sounds. Certain characteristics, particularly anatomical, could predispose their carriers to more intense modulations;
- assuming that when certain noise levels are exceeded, it is likely to generate nerve stimulation in the cochleovestibular system (Salt and Hullar 2010), the noise levels occasionally[9] encountered when taking the measurements showed that these levels can be exceeded outside homes, for frequencies below 20 Hz.

The phenomena described above were experimentally observed with intense pure tones (e.g. around a hundred dB SPL at 200 Hz in small laboratory animals, which is not necessarily the equivalent of very low-frequency sound in humans); whether they occur for noise exposure similar

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[9] From a few % of the time at 8 Hz to 20% of the time for 20 Hz at a distance of 500 m from the wind turbine. No frequencies below 8 Hz exceeded the various thresholds.

to that caused by wind turbines (prolonged, complex tones of lesser intensity) remains to be demonstrated.

The Working Group underlines that these physiological effects, often described by associations of residents living near wind farms, have an objective signature; for example, if there is a volume imbalance in the fluid of the inner ear, this is manifested as abnormal ENT test results, with higher sensitivity and specificity. And yet this signature has never been tested for in complainants.

These physiological effects are also reflected in symptoms (dizziness, tinnitus, nausea, etc.) that people know how to describe but are seldom mentioned; however the various testimonials collected during this expert appraisal more commonly described other types of effects, such as sleep and mood disturbances (depression, stress, anxiety, etc.).

✓ Ill-defined effects for exposure to very high-intensity infrasounds and low-frequency sounds

Exposure to very high-intensity infrasounds and low-frequency sounds (intensities 20 to 40 dB higher than those of wind turbines, thus delivering energy levels 100 to 10,000 times greater) is found in the workplace. However, its effects are controversial (non-specific effects, unsubstantiated and/or old data, etc.). The scientific situation is therefore unclear and the published recommendations on the limitation of occupational exposure can in no circumstances be transposed to this formal request.

✓ Unstable knowledge of the effects of prolonged exposure to lower-intensity infrasounds and low-frequency sounds

There are very few peer-reviewed publications addressing the issue of the potential effects of infrasounds and low frequencies produced by wind turbines. However, some studies have been undertaken for other noise sources, such as ventilation, heat pumps, compressors, road traffic, etc., for the same intensity levels as those emitted by wind farms. In these studies, self-reported disturbance (questionnaire) was the only observed health effect. No link was found with any physiological marker enabling a health effect to be identified. Nonetheless, these studies helped establish that a much higher sound level than that known for higher frequencies is required to perceive an infrasound and/or hear a low-frequency sound. Caution is required when extrapolating the above results to the situation of wind turbines.

✓ An observed *nocebo* effect

In parallel with these controversial results regarding the effects of prolonged exposure to low-intensity infrasounds and low-frequency sounds, several repeated double-blind experimental studies of very high scientific quality have shown negative effects and feelings in people who thought they were exposed to inaudible infrasounds when this was not necessarily the case. These negative effects and feelings were thought to be due to mere expectations about the harmful effects associated with this exposure.

This "*nocebo*[10]" effect helps explain why residents living near wind farms report stress-related symptoms. It is likely even greater in a context where there are multiple opposing arguments not only related to health (economic, cultural, regional, political arguments, etc.), conveyed in particular on the Internet, which can contribute to creating an anxiety-inducing situation.

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[10] The *nocebo* effect can be defined as a set of symptoms experienced by a subject undergoing something that is "seen as negative"; this may be medication, non-medicated therapy, or exposure to environmental factors. It is the opposite of the *placebo* effect, initially defined in medicine as a *"Substance improving a patient's symptoms whereas its phamacologically predictable efficacy should be nil or negligible".* The effect of the vector varies in both cases depending on the subject's expectations.

However, the occurrence of such a *nocebo* effect does not rule out the actual occurrence of health effects that it may potentially exacerbate.

Review of the epidemiological data

✓ Limited and inconclusive studies

Epidemiological studies should enable a comparison of the potential mechanisms for physiological effects with the health conditions observed in local populations. Unfortunately, such studies are limited in number and have exclusively dealt with the effects of audible noise from wind turbines on the health of local residents. None have focused on the health effects of infrasounds or low-frequency sounds emitted in the environment and more specifically produced by wind turbines.

All were cross-sectional studies and therefore did not provide grounds to affirm that the cause, i.e. exposure to noise from wind turbines, preceded the effect. The results observed in the majority of these studies were marked by selection biases or confounding factors. Only one of the analysed studies can be considered as of good scientific quality. It was also the only one that included not only subjective measurements but also objective measurements associated with the potential effects it examined. This study did not show any link between the level of audible noise from wind turbines and the health conditions self-reported by the respondents (sleep quality, dizziness, tinnitus, frequent migraines and headaches, chronic diseases such as heart diseases, hypertension and diabetes), stress levels, or perceived quality of life. The objective health measurements (cortisol levels in hair, blood pressure, resting heart rate and measured sleep quality) were consistent with the participants' reports. Again, these measurements were not linked to the level of audible noise from wind turbines. However, this study did show a link between this same level of audible noise and disturbance due to certain wind turbine characteristics (stroboscopic effect, flashing lights, vibrations, visual effect).

Given the small number of studies undertaken on this topic and their methodological shortcomings, it should be considered that no conclusions can currently be drawn as to the health impacts of noise from wind turbines.

■ Conclusions

Some residents living near wind turbines state that they feel health effects they attribute to the emitted infrasounds. Some situations of real malaise are encountered in these local residents, sometimes with medically observed health effects for which the causal link to exposure to infrasounds and low-frequency sounds produced by wind turbines cannot however be clearly established.

Exposure to infrasounds and low-frequency sounds from wind turbines is merely one of many assumptions reported (audible noise, visual and stroboscopic effects, electromagnetic fields, etc.) to explain these effects. This situation is not specific to wind turbines. It can be compared to those encountered in other areas such as electromagnetic waves.

It is currently very difficult to isolate the health effects of infrasounds and low-frequency sounds from those of audible noise and other potential causes related to wind turbines.

The measurement campaign undertaken by ANSES:

- confirmed that wind turbines are sources of noise whose spectrum of sound emission mainly contains infrasounds and low-frequency sounds;
- did not show any cases of the hearing thresholds for infrasounds and low frequencies (< 50 Hz) being exceeded.

Furthermore, according to the analysis of the literature:

- infrasounds may be felt by cochleovestibular mechanisms other than hearing at higher frequencies;
- physiological effects have been found in animals (cochleovestibular system) for high levels of infrasounds and low-frequency sounds;
- these effects have yet to be demonstrated in humans for the exposure levels related to wind turbines found in local residents (prolonged exposure to low levels);
- the connection between potential physiological effects and the occurrence of a health effect has not been documented;
- the expected symptoms in the event of cochleovestibular system disruption are not generally those reported by complainants; they seem mainly related to stress and can be found in wind turbine syndrome (WTS);
- a *nocebo* effect can be observed but clearly does not rule out the potential occurrence of other effects;
- due to its weak scientific bases, vibroacoustic disease (VAD) cannot explain the reported symptoms;
- no epidemiological studies to date have examined the health effects of infrasounds and low-frequency sounds produced specifically by wind turbines. At the present time, the only effect observed in epidemiological studies has been disturbance due to audible noise from wind turbines.

Recommendations of the collective expert appraisal

■ Improving the process for informing local residents during the construction of wind farms

In general, the health of the population partly depends on its level of information and participation in the implementation of development projects in its immediate surroundings.

When installing a wind farm near homes, the CES recommends:

- providing local residents with relevant information about plans for wind farms as early as possible (before the public inquiry). A guide should be prepared explaining the minimum information to be provided prior to the public inquiry;
- improving the visibility of public inquiries;
- broadening the scope of information and consultation to include all local residents potentially impacted by the project (considering its visual, noise impacts, etc.) without limiting it, as is currently the case, only to the sponsoring municipalities;
- mitigating the current state of access to a wealth of conflicting information, anxiety-inducing or not, available on the Internet, by providing the general public with regularly updated knowledge (dedicated website for example) and making it known to potentially impacted residents, before discussing plans for a wind farm.

Regarding the necessary dialogue between stakeholders concerning wind farms or plans for wind farms, the CES recommends:

- encouraging collaboration prior to plans for wind farms. As it is, project sponsors first request a building permit from the authorities by submitting an impact assessment for a finalised project, and the public inquiry occurs at the end of the process, thus minimising the weight of this inquiry in the decision-making process;

- better defining local stakeholders and further involving them in the dialogue.

■ Enhancing knowledge related to the exposure of local residents

In order to advance knowledge of exposure to infrasounds and low-frequency sounds, and considering how complicated they are to measure, the CES encourages:

- the use of standardised methods for measuring infrasounds and low-frequency sounds from wind turbines. The types of apparatuses used and the protocol or methodology to be followed to take reproducible and comparable measurements should be specified. The CES underlines that, given the high correlation between noise levels expressed in dBA and levels of infrasounds and low-frequency sounds for wind turbines, it could also be relevant to use methods for estimating infrasounds and low-frequency sounds based on measurements in dBA;
- the design of a model for predicting exposure to infrasounds and low-frequency sounds from wind turbines.

In order to improve comparability between data on exposure to noise produced by wind turbines, the CES recommends:

- developing an experimental method for characterising amplitude modulation;
- determining, as is the case for noise from transport[11], a single calculation method for predicting noise from wind turbines. It should take into account the various influencing parameters, to be used when undertaking noise impact assessments for ICPE authorisation requests.

■ Regulations

Systematically measuring the noise emissions of wind farms

The CES recommends systematically measuring the sound power of wind turbines *in situ*, before they are brought into service, in order to ensure that the sound characteristics of installed wind turbines are consistent with those specified in the impact assessment.

Drawing on practices in the airport sector, the CES also suggests, as soon as the farm is brought into service, setting up the systematic and continuous measurement of noise levels (audible noise and infrasounds and low-frequencies) from the wind farm, at one or more representative points, at the operator's expense. A simplified measurement method should be proposed in order to:

- monitor changes in noise levels in relation to the regulatory limit values and, when necessary, identify potential periods for which the regulatory limit values may be exceeded and determine the frequency;
- have noise measurements for comparison with the disturbance logs kept by local residents and look for possible correspondences between noise and reported disturbances.

If the regulatory limit values are repeatedly and significantly exceeded, the CES recommends defining specific criteria leading to actions that have yet to be determined (fines, forced shutdown, compliance measures, etc.).

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[11] NF S 31-133: Acoustics – Outdoor Noise – Calculation of Sound Levels.

The CES also recommends undertaking a campaign to measure the noise impacts of wind turbines using an expert appraisal method as defined by the Pr S 31-114[12] standard under preparation. The Working Group insists on the importance of taking measurements on property lines.

The CES points out that this type of practice has helped reduce tension around airports, since it provides objective data on exposure and helps better meet the expectations of local residents.

The appointment of a main contact person, in charge of monitoring this systematic measurement of exposure and responses to the requests of local residents, should be considered.

Limit values

The current regulations require a noise exposure limit on property lines (70 dBA during the day, 60 dBA at night) which in principle is not suited to infrasounds and low-frequency sounds from wind turbines, as it is expressed in dBA.

However, at the minimum distance separating wind turbines from homes (currently 500 m) and considering the particular profile of the spectra of wind turbines currently in operation, which enables a relationship to be established between levels in dBA and dBG for these noise sources, the CES considers that limit values expressed in dBA can already guarantee that exposure to infrasounds and low-frequency sounds in local residents (at the façades of homes) is below the commonly accepted hearing threshold (85 dBG).

Compliance with these limit values should thus protect local residents against any potential nuisance related to the audibility of the low and very low-frequency components of wind turbine noise. However, these limit values do not protect local residents from potential effects related to non-audible infrasounds and low-frequency sounds whose occurrence has yet to be demonstrated.

To reduce noise exposure in residents living near the oldest wind farms, and considering the acoustic performance of the most recent turbines, the CES recommends facilitating the replacement of old wind turbines with new ones by simplifying the related administrative process.

■ Improving knowledge regarding the relationship between health and exposure to infrasounds and low-frequency sounds

Experimental studies

Regarding the possible cochleovestibular mechanisms responsible for effects observed in laboratory animals and recent advances in techniques for non-invasive physiological measurements which can be taken within a few dozen minutes, the CES recommends undertaking additional studies in humans, in homes, using these techniques.

The tests already validated for the detection of abnormal homeostasis of cochlear sensory cells in patients with Meniere's disease could therefore be used (evoked otoacoustic emissions, spontaneous otoacoustic emissions, electrocochleography, videonystagmoscopy). These tests can all be performed in the field and repeated without discomfort. It would therefore be feasible to perform them on subjects, whether complainants (individuals describing symptoms of interest) or not, and whether or not they are exposed to very low-frequency sounds from the wind farm they live close to.

The implementation of a study demonstrating the objective signature of a physiological effect in complainants but not in non-complainants, only when the wind farm was in operation, could answer some major questions. These observations would not only help confirm a possible explanation but

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[12] Pr S 31-114: Measurement of outdoor noise before and after wind farm construction.

would also provide an opportunity to identify at-risk individuals and determine the physical threshold above which a specific risk emerges.

Epidemiological studies

Observing the health of residents living near wind farms, using epidemiological studies in particular, appears to be an obvious approach supplementing the expected advances in knowledge of physiological mechanisms. Requested by associations of local residents, carrying out such epidemiological studies nonetheless entails some methodological challenges, including a problem of statistical power due to the clearly limited number of individuals exposed to audible and inaudible noise from wind turbines, as well as the occurrence of countless biases that are often uncontrolled. Considering the large investment required to undertake such studies, as well as the possible relevance of the data they could generate, the CES supports the implementation of a feasibility study prior to such an epidemiological study.

Psychoacoustic studies

Considering the significance of the effects of audible sounds on disturbance caused by wind turbines, and given current gaps in this area, the CES recommends:

- undertaking additional studies on the loudness of complex low-frequency sounds (not only pure tones);
- developing, to that end, a study protocol for quantifying inter-individual variability in perception by undertaking hearing tests, etc.
- improving the characterisation of disturbance related to temporal variations in non-stationary audible noises and amplitude modulation in addition to other factors (visual, vibrations, etc.).

Neuroscience studies

Lastly, given the impacts of stress on health and the observed *nocebo* effect, the CES suggests promoting neuroscience research and in particular studies using medical imaging in order to identify the mechanisms involved.

4. AGENCY CONCLUSIONS AND RECOMMENDATIONS

The French Agency for Food, Environmental and Occupational Health & Safety endorses the conclusions and recommendations formulated above by the CES on "Physical agents, new technologies and development areas".

ANSES reiterates that wind turbines emit infrasounds (sound below 20 Hz) and low-frequency sounds. There are also other sources of infrasound emissions that can be natural (wind in particular) or anthropogenic (heavy-goods vehicles, heat pumps, etc.). The measurement campaigns undertaken during the expert appraisal enabled these emissions from three wind farms to be characterised.

In general, only very high intensities of infrasound can be heard or perceived by humans. At the minimum distance (of 500 metres) separating homes from wind farm sites set out by the regulations, the infrasounds produced by wind turbines do not exceed hearing thresholds. Therefore, the disturbance related to audible noise potentially felt by people around wind farms mainly relates to frequencies above 50 Hz.

The expert appraisal showed that mechanisms for health effects grouped under the term "vibroacoustic disease", reported in certain publications, have no serious scientific basis.

There have been very few scientific studies on the potential health effects of infrasounds and low-frequencies produced by wind turbines. The review of these experimental and epidemiological data did not find any adequate scientific arguments for the occurrence of health effects related to exposure to noise from wind turbines, other than disturbance related to audible noise and a *nocebo* effect, which can help explain the occurrence of stress-related symptoms experienced by residents living near wind farms.

However, recently acquired knowledge on the physiology of the cochleovestibular system has revealed physiological effects in animals induced by exposure to high-intensity infrasounds. These effects, while plausible in humans, have yet to be demonstrated for exposure to levels comparable to those observed in residents living near wind farms. Moreover, the connection between these physiological effects and the occurrence of a health effect has not been documented.

In this context, ANSES recommends:

Concerning studies and research:

- verifying whether or not there is a possible mechanism modulating the perception of audible sound at intensities of infrasound similar to those measured from local residents;
- studying the effects of the amplitude modulation of the acoustic signal on the noise-related disturbance felt;
- studying the assumption that cochleovestibular effects may be responsible for pathophysiological effects;
- undertaking a survey of residents living near wind farms enabling the identification of an objective signature of a physiological effect.

Concerning information for local residents and the monitoring of noise levels:

- enhancing information for local residents during the construction of wind farms and participation in public inquiries undertaken in rural areas;
- systematically measuring the noise emissions of wind turbines before and after they are brought into service;
- setting up, especially in the event of controversy, continuous noise measurement systems around wind farms (based on experience at airports, for example).

Lastly, the Agency reiterates that the current regulations state that the distance between a wind turbine and the first home should be evaluated on a case-by-case basis, taking the conditions of wind farms into account. This distance, of at least 500 metres[13], may be increased further to the results of an impact assessment, in order to comply with the limit values[14] for noise exposure.

Current knowledge of the potential health effects of exposure to infrasounds and low-frequency noise provides no justification for changing the current limit values or for extending the spectrum of noise currently taken into consideration.

Dr Roger GENET

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[13] Regarding minimum separation distances, those already set by the Grenelle 2 Act of 12 July 2010 (Article 90) have been maintained: 500 metres from any building for residential use or area intended for housing, 300 metres from a basic nuclear facility or ICPE.

[14] The noise emissions of a classified installation subject to authorisation must not generate, in noise aggravation zones, aggravation above the acceptable values.

KEYWORDS

Wind farm, wind turbine, low frequency noise, infrasound, risk assessment.

Wisconsin
Wind Siting Council

Wind Turbine Siting-Health Review

and

Wind Siting Policy Update

October 2014

October 31, 2014

Chief Clerk Jeff Renk
Wisconsin State Senate
P.O. Box 7882
Madison, WI 53707

Chief Clerk Patrick E. Fuller
Wisconsin State Assembly
17 West Main Street, Room 401
Madison, WI 53703

Re: Wind Turbine Siting-Health Review and Wind Siting Policy Update Pursuant to Wis. Stat. § 196.378(4g)(e).

Dear Chief Renk and Chief Fuller:

Enclosed for your review is the 2014 Report of the Wind Siting Council. This report is a summary of developments in the scientific literature regarding health effects associated with the operation of wind energy systems, and also includes state and national policy developments regarding wind siting policy. The Wind Siting Council has no recommendations to be considered for legislation at this time. On behalf of the Council, I wish to thank you for the opportunity to provide this report to the legislature.

Sincerely,

Carl W. Kuehne

Carl W. Kuehne
Wind Siting Council Chairperson

Enclosure

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Appendix L – Population Densities in areas of Midwestern Wind Energy System Development

1.0 EXECUTIVE SUMMARY

The Wind Siting Council offers this report to the Wisconsin State Legislature for its consideration with a copy given to the Public Service Commission of Wisconsin.

2009 Wisconsin Act 40 (Act 40) took effect on October 15, 2009. Act 40 created a policy framework to allow uniform local regulation of wind energy systems in Wisconsin. Wisconsin Statutes § 196.378(4g), created by Act 40, directed the Public Service Commission of Wisconsin (Commission or PSC) to promulgate rules to specify maximum restrictions that a municipality can impose on installation and use of wind energy systems throughout the state of Wisconsin. Act 40 also created Wis. Stat. § 15.797 which directed the Commission to appoint a Wind Siting Council (Council) to provide advice and counsel during the rulemaking process. Furthermore, Wis. Stat. § 196.378(4g)(e) directs the Council to provide a report on pertinent peer-reviewed literature of the effects of wind energy systems on human health to the Commission and the Wisconsin State Legislature, every five years. Wisconsin Stat. § 196.378(4g)(e) also requires the Council to study state and national regulatory developments regarding wind siting. The report may include recommendations for legislation. This report provides this literature review and also describes current policy trends with regards to wind energy system siting. This consensus report also has attached several appendices describing the positions of minority factions within the Council.

As required by Wis. Stat. § 15.797(1)(b), the Commission appoints a Council of 15 members[1] representing stakeholder categories with interests in or related to wind projects. One member is to have expertise on health impacts attributed to wind energy systems and be a member of the UW-system. This seat is currently vacant. The issues surrounding wind siting are complex and involve many competing policy priorities including protecting health and safety, complying with regulatory mandates, protecting the environment, preserving local government control, considering impacts to private property, and providing a reliable and affordable supply of energy. The make-up of the Council reflects these diverse interests. Each member of the seven stakeholder groups represented on the Council has their own unique view about how to balance these priorities.

The Council understands that the diversity of its membership and the volume of research on wind health and siting issues on all sides of the debate presents challenges. The Council agrees that the protection of public health and safety are paramount. Accordingly, the Council agreed prior to its investigation and preparation of this report to review facts and science with the awareness that not all scientific documents are of equivalent rigor or impact. Accordingly, more weight was given to some types of literature over others.[2]

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[1] See Appendix A for a description of Council member stakeholder groups and membership.

[2] See Appendix B for a detailed description of literature criteria.

Pertinent literature included empirical research, reviews, and opinion articles that were gleaned from peer-reviewed scientific journals and reports from governmental entities. The scope of literature that was used for the wind-health review was also generally restricted to literature that specifically focused on the effects of wind energy systems on human health or well-being. As part of the Council's work while developing its 2010 wind siting recommendations that led to the creation of the Commission's administrative rules relating to wind energy systems, Wis. Admin. Code ch. PSC 128 (PSC 128), the Council provided an exhaustive and then up-to-date review of pertinent wind-health scientific literature.[3] This report covers new information that has been published in the scientific literature from 2011 to 2014.

To prepare this report, Council members collected literature related to the effects of wind energy systems on human health. Commission staff also conducted a formal literature review. These efforts identified over 40 peer-reviewed publications on wind-health issues and three governmental reports.[4] Although the Council sought to provide the most detailed and complete literature review as possible, certain limitations were encountered. The Council had limited access to some non-publicly available articles and there is a relative paucity of current and diverse research on the effects of wind energy systems on human health and well-being.

The Council's conclusions and recommendations are detailed below.

Summary of Key Findings from Wind-health Literature

- Nine publications based on cross-sectional surveys of individuals living in the proximity[5] of utility-scale wind energy systems have been conducted or analyzed since the Council's 2010 recommendations.
- Some individuals living in the proximity of wind systems may experience annoyance[6] and a small fraction report sleep disturbance[7] due to wind turbine noise during operation.
- Some individuals report increases in stress due to wind turbine operation.
- Stress and sleep disturbance may be related to chronic health conditions.

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[3] The Council's 2010 report contained both general conclusions and siting recommendations as well as a minority, dissenting appendix.

[4] The Council agreed to offer greater weight to peer-reviewed literature on wind-health issues, as mandated by Wis. Stat. § 196.378(4g)(e). As such, the Council's conclusions are based upon the peer-reviewed literature. Appendix C contains discussion of governmental reports identified by the Council. Full citation of all articles included in this survey is provided in Appendix D.

[5] "Proximity" and "near" refer to distances less than 1.5 miles.

[6] "Annoyance" is used throughout this report to mean "a feeling of resentment, displeasure, discomfort, dissatisfaction or offence which occurs when noise interferes with someone's thoughts, feelings or daily activities", as used by the World Health Organization in its publication regarding occupational noise, available at http://www.who.int/quantifying_ehimpacts/publications/en/ebd9.pdf. Although this report relies on this definition, it should be noted that rarely do the empirical reports, reviews, and governmental reports cited herein provide the definition of "annoyance" under which the authors' conclusions were reached. Thus, caution is merited when comparing conclusions regarding "annoyance" throughout the published literature.

[7] Approximately 4 percent of respondents

- There are substantial individual differences in how people report their perception of wind energy systems and a negative perception affects whether an individual reports adverse health effects that they attribute to wind energy systems.
- The majority of individuals living near utility-scale[8] wind systems do not report stress, sleep deprivation, or chronic adverse health effects attributed to wind turbines.

The strength of these conclusions is complicated by two factors. First, although there are nine publications on surveys of individuals living near wind turbines, the conclusions from two studies are of limited scope. For instance, one article by Taylor et al. (2013) surveys individuals living near wind turbines that have a maximum generating capacity of 5 kilowatt (kW) or less. These turbines are thus substantially smaller than a typical utility-scale turbine and the conclusions of that survey may not be applicable to the usual wind-health discussion. A second survey by Krogh et al. (2011) was only conducted near existing wind systems where anecdotal reports of health effects have been reported. Therefore, without a control group and due to the use of biased[9] survey questions, it is difficult to apply that study's conclusions to other wind projects. Indeed the bias introduced in the Krogh et al. (2011) survey results in reports of negative effects (sleep disturbance and headache) attributed to wind turbines by over 70 percent of participants, which is unusually high compared to other studies where negative effects were reported. The limitations of available research confines the Council's survey to only seven pertinent, unbiased, cross-sectional studies, three of which use the same data set.

The limited empirical research on wind-health issues leads to the second complicating factor for the Council's survey. Many of the reviews and opinion articles published since 2011 that were included as part of this literature survey are centered on these seven studies.[10] Thus, each review/opinion article identified is not an independent appraisal of the available science, but rather a summary of the same information repeated multiple times. Consequently, broad statements such as there is "overwhelming evidence"[11] that wind energy systems negatively impact human health rely on a limited amount of actual empirical research and summaries of summaries.

Based on the available literature, what the Council can reasonably conclude is that some individuals residing in close proximity to wind turbines perceive audible noise and find it annoying. A small subset of these individuals report that this noise negatively affects their sleep

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[8] Turbines less than 100 kW in size are considered "small wind" under PSC 128 and are not subject to all of the same requirements as larger turbines. A typical utility-scale turbine generates at least 1.5 megawatt (MW) of electricity and 2.3 MW and larger turbines are currently operating in Brown County, Wisconsin and are being proposed for St. Croix County, Wisconsin. These higher capacity turbines are also proposed or are installed in other states and countries.

[9] "Bias" is used throughout this report to mean to have a tendency to show an unjustified prejudice towards an argument.

[10] Katsaprakakis 2012, Nissenbaum et al. 2012, Shepherd et al. 2011, Bakker et al. 2012, Pedersen 2011, Janssen et al. 2011, Mroczek et al. 2012

[11] Phillips 2011

and may result in other negative health effects. However, based on objective surveys near wind energy projects, it appears that this group is in the minority and that most individuals do not experience annoyance, stress, or perceived adverse health effects due to the operation of wind turbines. This conclusion is especially true if wind turbine siting is used to limit high noise exposure.

Summary of Regulatory Developments in Wind Siting

After reviewing the wind siting policies of all fifty states and the District of Columbia, as well as peer-reviewed literature regarding wind siting policy, the Council has concluded that Wisconsin's siting regulations for wind energy systems are consistent with other state and national policy regulatory developments.

No Recommendations for Legislation

Wisconsin's wind siting rule, Wis. Admin. Code ch. PSC 128, is the product of an extensive and transparent review process and has been in effect since March 16, 2012. Absent any specific information arising from a wind project reviewed and approved under PSC 128, and based on the survey of peer–reviewed scientific research regarding the health impacts of wind energy systems, and the study of state and national regulatory developments regarding the siting of wind energy systems, the Council majority finds no reason at this point to recommend legislation regarding the siting of wind energy systems.

2.0 THE COUNCIL AT WORK

Wind Siting Council Membership

Recognizing that there are many complex, diverse, and sometimes controversial issues involved in wind turbine siting, the Legislature prescribed a very diverse and explicit membership to the Council. Wisconsin Stat. § 15.797(1)(b) directs the Commission to appoint a Wind Siting Council of up to 15 members to, among other things, advise the Commission in its rulemaking process, provide pertinent information regarding wind siting policy, and survey the wind-health literature.

Wind-health Report Drafting

The Council first met to discuss the drafting of this wind-health review and policy update in mid-December, 2012. At that meeting, the Council developed a tentative timeline for report drafting. At the next meeting in early March, 2013, the council agreed upon the types of literature that would be considered in its survey and on a date before which to compile a literature list. Council members also agreed to have Commission staff assist them in drafting this report. By the beginning of May, 2013, Council members had submitted the literature they wished to be included in the report and Commission staff had conducted a formalized wind-health literature review. In mid-August, 2013, Council members received a list of all pertinent literature that was identified for this survey to facilitate the drafting process.

Commission staff then prepared a draft report for the Council to review. The Council's review began in February of 2014 and continued through multiple iterations of discussion and revision. In May of 2014, the Council voted to adopt this wind-health report, including the dissenting minority report that is attached as an appendix.

Wind-policy Update Drafting

In September, 2013, the Council was asked to provide to Commission staff any documents they would like to consider for the wind siting policy update. The Council did not identify any information beyond the 2012 National Association of Regulatory Utility Commissioners (NARUC) wind siting best practices.[12] Commission staff further surveyed all American states' policies to evaluate national policy trends.

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[12] Stanton 2012

3.0 COUNCIL REVIEW OF WIND TURBINE-HEALTH LITERATURE

Survey of Peer-Reviewed Literature

The first large utility-scale wind turbines in Wisconsin went online in the late 1990's. From the outset of this newly implemented technology, there was considerable debate in different political subdivisions regarding the siting of wind turbines. As wind energy systems increased in size and capacity, some of this debate turned to the possible impacts that turbine operations may have on human health. Concerns about potential adverse health effects led to a formal regulatory framework in 2009 with the passage of Act 40 and creation of Wis. Stat. § 196.378(4g) which requires the Council to, among other things, provide recommendations on wind turbine siting criteria for rulemaking purposes and survey current, peer-reviewed literature on health impacts. As part of its recommendations to the Commission regarding wind siting rules, the Council completed its initial survey of the wind-health literature in 2010. The majority of the members concluded that given appropriate siting measures, including 50/45 dB(A) day/night noise limits, 1,250-foot wind turbine setback, and less than 30 hours of shadow flicker per year for non-participating residences, it is reasonable to conclude that adverse health effects would be unlikely to occur. These conclusions were codified in PSC 128 which describes the wind siting rules that the Commission considers when reviewing wind energy projects and the siting criteria that local governments may not be more restrictive than.

With over 400 utility-scale wind turbines installed throughout Wisconsin, some members of the public have continued to express concerns over potential adverse human health effects attributed to wind turbines. When wind energy systems were initially being proposed, the potential adverse health effect causes that people were concerned with included noise, shadow flicker, electromagnetic fields (EMF), stray-voltage, ice-throw, and physical collapse of the turbine. As wind energy has expanded, the most common issue that is now being studied with regard to impacts on individuals residing in close proximity to wind turbines is noise generated by the moving blades, electric generator, and mechanical yawing mechanisms. The level of public concern and amount of scientific or technical research associated with other potential adverse health causes have diminished.

In this five-year review, the Council surveyed scientific research, analysis, and opinions on the issue of wind energy systems and health that have been published since its 2010 recommendations to the Commission.[13] The Council conducted this survey using the operational definition of health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."[14] As noted above, the focus of this survey is generally on the effects of wind turbine-generated noise, as this is the primary area where academic research is being conducted and the only such cause studied in the peer-reviewed publications identified

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[13] See minority appendices E and F for further discussion of potential adverse health effects associated with wind energy systems.

[14] World Health Organization definition of health, available at http://www.who.int/about/definition/en/print.html.

by the Council. In addition to surveying literature that was identified by Council members, Commission staff also conducted a formal literature search in March of 2013, using the academic search engine ISI Web of Knowledge. Search terms included wind turbine and health, noise, low-frequency noise, infrasound, or shadow flicker. This search was repeated, using the same search criteria, in December 2013 to identify any articles that were subsequently published. All peer-reviewed publications that were relevant and available were collected. This group of papers was then narrowed to those published in 2011 or later for inclusion in this report. Additional publications were referenced in the Council's report as they became available in 2014, however a formal literature search was not conducted after December 2013.

Empirical Research

One of the most powerful measures to assess potential adverse health effects caused by utility-scale wind turbines are the results from epidemiological studies. The Council identified a number of cross-sectional, survey-based studies. These types of studies are common because they are easy to conduct, inexpensive, and can determine baseline prevalence of impacts across communities. They are, however, limited because they are not experimental and therefore cannot show absolute cause and effect. They are also limited in that they are subject to bias, discussed below, and they are a snapshot and are not able to establish trends. The Council's review of the wind-health literature revealed nine publications on cross-sectional surveys of individuals living near wind farms, related to health.[15] Of these nine publications, four appear to be unbiased with large sample sizes,[16] three have small sample sizes, limiting the reliability of their conclusions, and applicability of the other two is limited due to scope or study design.

Caution may be warranted when reviewing these surveys as they are subject to different, and sometimes overlapping, biases due to study design. These include observation, confirmation, and selection bias. Observational bias results when authors limit the scope of a study to a particular area or issue, in particular an area or issue where results are expected to be found while disregarding other information. This bias makes a positive result more likely than if a randomized sample was surveyed. Confirmation bias encompasses a range of effects that can be described broadly as a tendency to draw conclusions that are in keeping with pre-established beliefs. It can arise through the way data is collected, such as disregarding evidence that would be in conflict with anticipated results. Selection bias has to do primarily with failure to select study subjects that accurately represent the population or by allowing subject self-selection. For instance, performing a survey through an open, online means may select for those individuals motivated to participate rather than a cross section of a population.

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[15] Bakker et al. 2012, Pedersen 2011, Nissenbaum et a. 2012, Shepherd et al. 2011, Katsaprakais 2012, Krogh et al. 2011, Taylor et al. 2013, Janssen et al. 2011

[16] Note, however, that these publications use the same source data set.

In addition to these biases in research design, there is also personal bias. As with any contentious field of academic study, some authors of the articles cited in this report may have interests in one area of argument. For instance, some authors reach the conclusion that wind turbines cause adverse health impacts by relying on evidence that other authors deem unreliable. The source of funding for some of the articles cited herein may also be from organizations that support or oppose wind energy. This may or may not influence the authors' perspectives on the wind-health issue. What is clear is that the majority of the articles cited in this report are peer-reviewed and that, regardless of the opinions of the article authors, outside experts have opined that the articles offer some degree of independence and important scientific information.

Surveys with Large Sample Sizes

The largest analysis (1,755 respondents) was conducted by Pedersen (2011) and involved three cross-sectional surveys in the Netherlands and Sweden using similar survey designs to evaluate the effect of environmental noise on health and well-being.[17] Respondents could indicate their level of annoyance from any sort of environmental noise. In all three surveys, most respondents did not report annoyance or adverse health effects associated with environmental noise. For those individuals that did report annoyance, it directly correlated to environmental noise, including noise generated by wind turbines. Surveys from two of the three wind energy systems also indicated that sleep interruption was related to environmental noise, including wind turbine noise. All three surveys also indicated that environmental noise is associated with stress. The study's author suggested that stress from environmental noise may cause a positive feedback loop between stress and sleep disturbance, where stress causes sleep disturbance which in turn causes more stress. Although annoyance, sleep disturbance, and stress were linked to environmental noise, the authors point out that these effects are only attributable to wind turbines when they are generating sound levels over 40 dB(A),[18] a sound level that can be avoided through proper siting[19] and which is greater than some European regulatory limitations.

Bakker et al. (2012) conducted a separate analysis on a subset of the data (725 respondents) gathered in the Netherlands by Pedersen (2011).[20] This analysis again showed that the majority of respondents did not identify environmental noise from wind turbines as annoying. Twenty-three percent of respondents did report annoyance from wind turbine noise to some degree while outdoors and 14 percent reported annoyance from turbines while indoors. This annoyance was directly related to noise level, with approximately 4 percent of annoyed respondents reporting annoyance where sound levels were less than 30 dB(A) and approximately 66 percent where they were above 45 dB(A), a trend that is also supported by experimental evidence by Ruotolo et al. (2012). This analysis also examined sleep disturbance in greater detail. Sleep disturbance was reported by approximately 33 percent of respondents and it increased with greater environmental

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[17] Survey participants lived within 1.5 miles of multiple wind turbines with a capacity of at least 0.5 MW.
[18] Wisconsin's wind siting rules limit day noise to 50 dB(A) and night noise to 45 dB(A).
[19] To be discussed in further detail below.
[20] Survey participants lived within 1.5 miles of multiple wind turbines with a capacity of at least 0.5 MW.

noise levels. However, of these individuals, 86 percent attributed their sleep disturbance to people, animals, or traffic/mechanical noise and 14 percent (approximately 4 percent of total respondents) indicated that wind turbine noise interrupted their sleep. The authors' data indicate that most people living near wind energy systems are not annoyed by environmental noise and that there is limited support for wind turbine-caused stress leading to physiological distress, especially in urban areas with other environmental noise.

These same survey data collected by Pedersen (2011) were further analyzed by Janssen et al. (2011) to determine if respondents found wind turbine noise to be qualitatively different than other sources of environmental noise as well as to identify what variables may affect annoyance.[21] The authors found that respondents were more annoyed by wind turbine noise than by road or rail noise when above 40 dB(A) and aircraft noise when above 45 dB(A), [22] possibly due to the characteristics of wind turbine noise which modulates in amplitude and frequency.[23] Those who benefited economically from wind energy systems reported less annoyance by wind turbines than those who did not receive an economic benefit.[24] Those who considered themselves to be more sensitive to noise, individuals who could see a turbine from their residence, and middle-aged individuals reported more annoyance by wind turbines than individuals who did not fall into any of those categories. The former result regarding sensitivity is supported by an experimental study by Ruotolo et al. (2012) from which the authors conclude that noise sensitivity is positively correlated with annoyance. Janssen et al. (2011) also concluded that annoyance from environmental noise increases rapidly as sound levels exceed 35 dB(A) outdoors and 40 dB(A) indoors. The study authors found this to be especially true for wind turbine noise, with a large number of individuals reporting to be both annoyed or highly annoyed by wind turbines producing outdoor (approximately 40 percent of respondents) or indoor (approximately 18 percent of respondents) sound levels over 45 dB(A).[25]

In a separate study, Mroczek et al. (2012) examined the potential for quality of life impacts, including health-related quality of life effects, through a survey of 1,277 randomly-chosen adults residing in areas near wind farms. Study participants were given standard and scientifically accepted quality of life questionnaires assessing physical and mental health. These questionnaires were supplemented with questions about distance between a house and a wind farm, age, gender, education, and professional activity. Contrary to arguments commonly made about the health impacts of wind turbines to near-by residents, statistical analysis of the responses found that quality of life was reported to be the best across all categories by the respondents living the closest to wind farms, while the worst by those living farther than 4,900 feet from a wind farm. In particular statistically significant trends included people living more

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[21] Survey participants lived within 1.5 miles of multiple wind turbines with a capacity of at least 0.5 MW.

[22] James 2011

[23] Renterghem et al. 2013, Fiumicelli 2011, van Renterghem et al. 2013

[24] As also found by Bakker et al. 2012

[25] These percentages are calculated from polynomial best fit formulas provided by the study authors. Substantial uncertainty exists for this value because of a low sample size of individuals that experience sound levels over 40 dB(A).

than 4,900 feet from a wind farm assessing their vitality significantly lower than those living in the closest distance to a wind farm. Similarly, mental health and social functioning assessments were lower for those living over 3,280 feet from a wind farm as compared to those living closer. Mroczek et al. (2012) therefore conclude that "close proximity of wind farms does not result in the worsening of the quality of life."

Surveys with Limited Sample Size or Scope

In another study, Katsaprakakis (2012) reviewed the potential environmental and health impacts associated with wind energy systems and conducted a small survey of 100 individuals on their opinions regarding wind turbines. As in the previous surveys, the author found that wind turbines generally do not cause adverse health effects and that the primary concern associated with wind turbines is noise generated during operation (approximately 35 percent of respondents). This survey also found that in general people are supportive of wind energy and the author concludes that, with proper siting,[26] there are no statistically documented adverse health effects associated with wind turbines.

Shepherd et al. (2011) came to somewhat contradictory conclusions using measures of quality of life. In a survey of 39 individuals living within 1.2 miles of 2.3 MW wind turbines (and compared to 158 individuals living further away from the same wind turbines), the authors found that individuals residing in close proximity to turbines reported reductions in sleep quality, energy, and overall quality of life. This survey also indicated that there is great interpersonal variation in opinions on wind projects and concluded that individuals that report greater perceived noise sensitivity are more likely to report annoyance,[27] reduced sleep quality, and lower psychological and social well-being. A separate survey by Nissenbaum et al. (2012) of 38 individuals living within 0.8 miles of 1.5 MW wind turbines (and compared to 41 individuals living further away) in Maine showed similar results. This survey found that when compared to people living further than 0.8 miles from turbines, those individuals living within 0.8 miles reported worse sleep quality, were sleepier during the day,[28] and reported worse mental health scores. The authors also described a dose response curve where adverse health effects are inversely related to distance from a turbine.[29] Although the findings of both of these studies are in agreement, caution is merited as the sample size in both is small, limiting the conclusions and reducing the ability of the surveys to reveal adverse health effects.

Taylor et al. (2013) conducted another relatively small survey (138 respondents, approximately 11 percent return rate) in the United Kingdom of individuals living within 0.62 miles of a wind turbine. The authors concluded that perceived noise rather than actual turbine noise is a

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[26] To be discussed in further detail below.

[27] A finding similar to that of Janssen et al. 2011 and Ruotolo et al. 2012

[28] Note that with regards to both sleep quality and daytime sleepiness, although the authors concluded that differences exist between the near and far groups exist, both groups reported values that fall under "poor sleep quality" and "not sleepy" when their scores are indexed against standard classifications.

[29] This trend was only significant after controlling for age, gender, and household clustering.

predictor of negative, non-specific adverse health effects. Furthermore, the authors concluded that individuals who have a negative attitude towards wind turbines are more likely to experience adverse health effects, regardless of actual noise levels. These conclusions suggest that perceived adverse health effects associated with wind turbines are greatly influenced by an individual's perception or acceptance of wind turbines rather than actual, physiological effects. Although these findings are compelling, they have limited applicability to wind energy in Wisconsin. As with Shepherd et al. (2011) and Nissenbaum et al. (2012), this study had a low response rate which can introduce bias due to certain population segments being over or under-represented and the authors also restricted their survey to individuals living near turbines rated at a capacity of 5 kW or less. This is orders of magnitude below the capacity of wind turbines that are generally installed in utility-scale wind systems and below the capacity that is generally the target of public concern in Wisconsin.

In another study with limited applicability, Krogh et al. (2011) used an open, online survey to evaluate wind turbine caused adverse health effects in Canada.[30] The authors found that 94 percent of respondents self-reported altered health or quality of life and specifically that 72 percent of participants reported experiencing stress, depression, and sleep disturbance due to wind turbines. Although these findings are striking, it should be noted that there are several limitations on using the survey results due to the study design. First, this study was not conducted via a random sample and it may be that individuals who have negative opinions about wind energy were more motivated to fill out the survey and are therefore overrepresented. Second, the survey design used biased questions. For instance, Question 8 asks, "Do you feel that your health has in any way been affected since the erection of these turbines?" These types of questions predispose respondents to negative responses and are atypical when compared to the more robust surveys reviewed here.[31] Finally, the authors use a p-value[32] that is less conservative than the established scientific norm to establish significance. These limits severely reduce the applicability of this study when considering potential adverse health effects of wind turbines in the general population.

Other Research on Impacts to Individuals Residing in Close Proximity to Wind Farms

As of the writing of this report, there is also a small but growing body of research related to the health impacts of wind turbines that does not take the form of the surveys discussed above. This includes research on other factors that could impact reported symptoms, as well as broader research modeling and analyzing the population-level health impacts related to wind energy.

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[30] Participants lived from 0.2 to 1.5 miles from a wind turbine.

[31] For example Pedersen 2011

[32] In this case, p-value refers to the acceptable probability of finding a significant result where one does not exist. A p-value of 0.05 is used for most scientific study to establish significance, meaning a false-positive chance of 5 percent is acceptable. The authors of this study used p-values up to 0.1 to establish significance, or a 10 percent acceptable false-positive probability.

Using a double-blind design, Crichton et al. (2013a), examined the importance of individuals' differences in perception of wind turbines in predicting perceived adverse health effects. The authors informed half of a group of healthy individuals that infrasound causes adverse health effects (high-expectancy group) and the other half that it does not (low-expectancy group). Individuals were then exposed to infrasound and sham infrasound (told they were exposed when they were not). Individuals from the high-expectancy group reported more adverse health effects than from the low-expectancy group and also reported adverse health effects at the same level during actual and sham exposure. In a follow-up study using a similar experimental design, Crichton et al. (2013b) informed study participants that infrasound either improves health or causes health problems. The study authors report that when actually exposed to infrasound, those participants reported feeling better or worse, in accordance with which expectancy group they were in. Taken together, these studies indicate that individual differences and expectations (psychogenic factors) appear to be more important in predicting perceived infrasound-caused adverse health effects than other factors, including actual exposure. However, these conclusions are limited because both studies were conducted exclusively on college students and had small sample sizes.

In research looking more broadly at importance of psychogenic factors in reported symptoms, Chapman et al. (2013) examined the spatial and temporal distribution of noise or health complaints with regard to wind farms in Australia. Recorded complaints from all 51 Australian wind farms from the period 1993-2012 were compiled, corroborated, and analyzed as part of the study. The authors examined the relations within complaints, and the relation of complaints to other known factors, such as distance to wind turbines and timing with regard to dissemination of health concerns by interest groups. Chapman et al. (2013) found that the majority of wind farms had no history of complaints, and that less than 1% of residents within 1km of wind farms with large (>1MW) turbines complained. It was also found that the timing of complaints with regard to wind turbine operation was "inconsistent with turbines causing acute effects", which supports the conclusion of Taylor et al. (2013) that "it is the perception of noise rather than actual noise that is important in predicting symptoms of ill-health."

Research Conclusions

There is a relative paucity of empirical, epidemiological studies on the effects of wind turbines on human health and well-being.[33] Within the literature that does exist, there are also some apparently contradictory results. Based on the strength of the information that is available, it is reasonable to conclude that the majority of individuals living near wind energy systems do not experience adverse health effects or reduced well-being.

It should be noted that a small minority of individuals living in close proximity to wind turbines are annoyed by wind turbine noise and of these, some experience sleep disturbance and stress.

[33] With this said, the Council recognizes that much important and groundbreaking research is being conducted in the wind-health field.

It is currently not possible, based on available research, to conclude with scientific certainty whether these adverse health effects are caused by wind energy systems. Furthermore, there exists empirical research suggesting that these issues are affected by factors including expectations of health impacts and personal attitudes and opinions with regards to wind energy systems.

Reviews and Opinions

The majority of the articles that the Council identified through its literature search are review and opinion articles. Review articles are useful in that they offer expert summaries of relevant literature, but they are also limited if available research is of modest quantity and quality. Although multiple cross-sectional studies have been administered in areas with wind energy systems, as noted above one of these studies is not applicable to wind energy issues in Wisconsin, another is biased, and several of the analyses conducted on surveys with large sample sizes used the same data set. For these reasons, it is necessary to view the over twenty review and opinion articles that deal directly with wind-health issues with caution. Rather than being reviews of a large body of independent primary literature, they represent syntheses of a handful of studies[34] and some are published by authors working actively for or against the wind energy industry.[35] Furthermore, some of the reviews that have been published misinterpret the results of the empirical research,[36] make claims of a causal link between wind turbines and adverse health effects without providing any evidence or citations,[37] or make erroneous claims about wind-energy policy.[38] With that said, there are several unbiased reviews that accurately interpret the primary literature and reach meaningful and balanced conclusions.[39]

Review and opinion articles on the wind-health issue generally fall into one of two categories, either supporting the claim that wind-generating facilities cause adverse health effects[40] or disputing the claim that actual physiological adverse health effects exist as a result of exposure to wind turbines.[41] What is not under dispute between these two groups is that wind turbines produce environmental noise, that some individuals find that noise annoying, and that environmental noise may cause sleep disruption if the sound levels are high enough. There is, as a result, a consensus that proper wind turbine siting is imperative when designing wind generating systems to reduce the impacts of noise on people.[42]

[34] See Horner et al. 2011
[35] See Moller and Pedersen 2011
[36] For example Hanning and Evans 2012, Phillips 2011
[37] For example Havas and Colling 2011, Phillips 2011
[38] For example Vanderburg 2011
[39] Roberts and Roberts 2013, Knopper and Ollson 2011, Fiumicelli 2011
[40] Phillips 2011, Havas and Colling 2011, Horner et al. 2011, James 2011, McMurtry 2011, Salt and Kaltenbach 2011, Shain 2011, Rand et al. 2011, Ambrose et al. 2012, Bronzaft 2011, Hanning and Evans 2012, Harrison 2011, Jeffery et al. 2013, Farboud et al. 2013, Arra et al. 2014
[41] Knopper and Ollson 2011, Thorne 2011, Bolin et al. 2011, Crichton et al. 2013(b), Moller and Pedersen 2011, Roberts and Roberts 2013
[42] See Krogh 2011, Shepherd and Billington 2011

The hypothesized route by which adverse health impacts arise among the review and opinion articles that can generally be characterized as against wind energy systems follows two paths. The first, and more compelling, hypothesized argument is that there is an indirect effect by which noise from wind turbines can cause annoyance and stress in individuals, that stress and noise may lead to sleep deprivation, and that these factors can act together or separately to cause adverse health effects.[43] Some of the adverse health effects that are commonly described include tinnitus, difficulty concentrating, hypertension, depression/anxiety, difficulty in diabetes control, and fatigue.[44] While many arguing that wind energy is safe claim that any health effects are secondary and due to individuals' reactions to wind turbines,[45] opponents of this argument assert that adverse health effects are caused by wind turbines, regardless of whether they are by secondary pathways.[46]

The second hypothesized pathway by which adverse health impacts arise is more contentious. Several authors provide case studies describing their experience working near wind energy systems as well as anecdotal reports of adverse health effects experienced by residents living near wind turbines.[47] The mechanism leading to adverse health effects suggested in these case studies is not the annoyance-stress-health effect pathway that has been outlined above, but rather physiological disease caused by inaudible infrasound and low-frequency noise (ILFN).[48] The authors concede ILFN is generally not perceived by humans at the sound pressure levels produced by wind turbines. Rather, they point to a mechanism described by Salt and Kaltenbach (2011) in which ILFN stimulates individuals' outer hair cells in the outer ear, causing a neurological impulse, but one that is not physically perceived by humans. The authors suggest that these unperceived impulses then cause chronic, physiological adverse health effects. They also suggest that effects of ILFN could also be exacerbated by resonance that may occur in rooms that meet the resonant frequency of long-wave ILFN[49] or because of the pulsing nature of turbine noise. This argument has been adopted by other scientists and is supported in both technical review articles[50] and an opinion article published in a medical journal.[51] However, there appears to be a dearth of empirical research on the purported ILFN-adverse health effect link and only one principle investigator is actively pursuing a research program on the effect of ILFN on outer hair cell stimulation.[52]

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[43] Jeffery et al. 2013, Bronzaft 2011, Shain 2011, Horner et al. 2011, Phillips 2011, Arra et al. 2014
[44] See McMurtry 2011 for an exhaustive list of symptoms and a medical case definition.
[45] Knopper and Ollson 2011
[46] Horner et al. 2011, Shepherd et al. 2011, Bakker et al. 2012
[47] Ambrose et al. 2012, Rand et al. 2011
[48] Infrasound is generally considered sounds below 20 hertz (Hz) and low-frequency noise is generally considered sounds between 20 Hz and 200 Hz.
[49] Havas and Colling 2011
[50] Havas and Colling 2011, James 2011, Farboud et al. 2013
[51] Hanning and Evans 2012
[52] Alec N. Salt at Washington University, St. Louis, MO

As noted previously, in no instance in the Council's literature survey did an article make the claim that wind turbines have no effect on individuals living near them. Rather, the view of those authors in the relatively pro-wind category is that they can cause annoyance, may cause sleep disturbance, and may cause some stress due to environmental noise and a loss of control over the environment.[53] Although these effects may be viewed by some as adverse health effects, another group of articles concludes that there is not a direct link between wind turbines and negative effects in human health[54]and that wind turbines do not elicit more complaints of adverse health effects than other types of novel environmental noise.[55] Furthermore, these articles indicate that the primary predictor of whether an individual will report adverse health effects subsequent to a wind energy facility coming online is the individual's perceptions of wind turbines.[56] In other words, these authors argue that an individual's disposition (positive or negative) towards wind turbines is a powerful predictor of whether they will report adverse health effects.

There is also no debate in the literature that wind turbines produce ILFN and that larger wind turbines generally emit more audible noise than smaller turbines. Larger turbines also emit higher levels of low-frequency noise, but not substantially larger amounts of infrasound,[57] and actually produce less infrasound than some other sources of environmental noise.[58] In reviews and opinion articles that are not critical of wind turbines, the conclusion is that ILFN at the level produced by turbines does not lead to adverse health effects[59] and that there is no scientifically accepted physiological pathway that would cause such effects.[60]

The Council's survey also identified reviews and opinion articles that dealt with noise limits and potential health effects. Some concern is presented that wind turbine noise modelling is inaccurate[61] and that noise limits are inadequate.[62] However the former claim is disputed by testing of actual wind energy systems which suggest that noise levels do not differ significantly from those predicted by a common noise modelling software program.[63] The latter will be addressed in the policy update section of this report.

The Council's survey of review and opinion articles identified more articles that were critical of wind energy systems than in support (15-critical, 7-supportive). This does not indicate that the consensus of the scientific community is that wind energy facilities have proven adverse health effects in humans, however. Although the reviews and opinion articles that are not critical of

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[53] Knopper and Ollson 2011, Roberts and Roberts 2013, Bolin et al. 2011
[54] Roberts and Roberts 2013
[55] Knopper and Ollson 2011
[56] Knopper and Ollson 2011
[57] Moller and Pedersen
[58] Bolin et al. 2011
[59] Roberts and Roberts 2013, Knopper and Ollson 2011, Bolin et al. 2011
[60] Bolin et al. 2011, Roberts and Roberts 2013
[61] Thorne 2011
[62] Palmer 2013
[63] Kaldellis et al. 2012

wind energy are fewer in number, other factors are also important when evaluating these articles. For instance, many of the critical reviews and opinion articles are published in very low-impact[64] journals, make erroneous claims, and do not follow scientific standards on citing evidence. This point is made not to discount the importance of considering critical reports, but rather to emphasize that multiple factors must be considered when evaluating publications on important public health issues.

Conclusion

Although there are several publications arguing that noise from wind turbines directly causes adverse health effects in humans, based upon the peer-reviewed literature, it appears at this time that there is insufficient data to validate this scientific conclusion. It will be a priority of the Council to continue surveying the peer-reviewed literature to determine if this consensus changes, if a viable mechanism for ILFN-caused adverse health effects is shown, and if the medical community identifies a disease associated with wind turbine-noise exposure. Although important and indeed groundbreaking research is clearly being conducted in the field of wind-health interactions, the Council is unable, at this time, to conclude that wind turbines have a direct and negative effect on human health.

As it stands, the literature available to the Council lacked strength and in some instances, was biased. Many of the authors of the material cited herein point this out and call for more detailed, randomized, long-term studies in the future. The Council is aware of at least one study[65] being conducted by a government panel that is designed to do just that and at least one additional governmental review of the literature.[66] These may shed light on new health issues associated with wind turbines or confirm the Council's finding that there is no direct link between wind turbines and human health. At the very least, ongoing research should clarify the sometimes muddy waters of the wind-health debate.

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[64] "Impact factor" is a calculation based on the number of times a journal is cited over the total number of all citations in a given time period and is a proxy of importance. High-impact journals carry more weight, prestige, and influence than low-impact journals.

[65] Government of Canada, Health Canada and Statistics Canada Group

[66] Government of Australia, National Health and Medical Research Council

4.0 WIND SITING POLICY UPDATE

Under Wis. Stat. § 196.378(4g)(e), the Council is charged with reviewing regulatory developments in wind siting policy and providing a report and recommendations to the Legislature. Working towards this end, the Council reviewed the wind siting policies of all fifty states and the District of Columbia.[67] Commission staff also conducted a formal academic search of the peer-reviewed literature regarding wind siting policy. This survey was completed in November 2013 and used the academic search engine ISI Web of Knowledge. Search terms were designed to gather results both on general wind siting policies as well as pertinent developments regarding the specific rules contained in PSC 128.[68] Terms regarding noise and health or shadow flicker were not included as these were used in the formal academic search that was conducted as part of the wind-health section of this report and have been addressed earlier in this report. These searches and a review of news reports identified two non-governmental reports on wind siting policy, three white papers on the effects of wind energy systems on residential home value specifically, and eight peer-reviewed articles.[69,70]

While the Council considered all of these documents, the Council heavily relied upon the comprehensive 2012 report commissioned by the National Association of Regulatory Utility Commissioners (NARUC report).[71] NARUC is a national association representing state public service commissioners and acts as a resource for state utility regulatory agencies. It commissioned a report on wind siting policies under a grant from the United States Department of Energy, and the NARUC report is an extensive policy document regarding wind siting in the United States.

Rules on the siting of wind energy systems in Wisconsin are codified in Wis. Admin. Code ch. PSC 128 and have been in effect since March 16, 2012. These rules apply to local regulation of wind energy systems with a total combined generating capacity of less than 100 MW, and they limit the restrictions that a local jurisdiction may impose on a wind energy development in Wisconsin. Wind energy developments of 100 MW combined generating capacity or greater are subject to Commission review. The Commission is not required to strictly adhere to Wis. Admin. Code ch. PSC 128, however it must consider the requirements in its review of a

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[67] See Appendix G for the results of this review.

[68] Search terms included “Wind siting policy,” “Wind siting rule,” “Wind turbine setback distance,” “Wind turbine noise limit,” “Wind turbine property value,” “Wind turbine siting,” and “Wind turbine decommissioning.” In total, these terms elicited 398 hits, of which 8 were in some way relevant to wind turbine siting or health.

[69] This survey also identified three articles regarding noise and health that were published after and one that was not identified by the Commission staff’s academic survey. These are included in the wind-health portion of this report.

[70] Two articles identified, Fargione et al. 2012 and Mulvaney et al. 2013, are relevant to wind policy issues, however they do not apply to issues that the Council has addressed here. Fargione et al. 2012 recommends a mapping process to identify wind turbine sites that are optimal in terms of mitigating harm to wildlife. Mulvaney et al. 2013 conducted a survey of individuals living near proposed or actual wind energy systems in Indiana and concluded that most people living near wind energy projects are supportive, primarily for financial and environmental reasons and that those opposed are more vocal in their opposition and are often exurbanites who moved to a rural area for the lifestyle.

[71] Stanton was commissioned by NARUC to prepare the 2012 report and views or opinions reached therein are not necessarily those of NARUC or the US DOE.

proposed wind energy system. Wisconsin wind siting rules are some of the most comprehensive in the nation, covering nearly every aspect of wind siting, and include:

- 50 dB(A) day and 45 dB(A) night noise limits.
- Turbine setback from property lines, roads, and utility rights-of-way of 1.1 times turbine height.
- Turbine setback from non-participating residences of 3.1 times turbine height, up to 1,250 feet.
- A maximum of 30 hours of shadow flicker per year at non-participating residences and mitigation if over 20 hours.
- Mitigation of radio and television interference.
- Testing of stray voltage by the wind energy system owner, if requested.
- Proof of financial responsibility for decommissioning.

Findings Related to Wind Siting Rules under PSC 128

Outlined below is a discussion of major state and federal policies regarding wind siting.

Jurisdiction

The NARUC report's exhaustive review of wind siting policies in all of the United States found that jurisdiction over wind energy developments is held at the state level in 22 cases, the local level in 26 cases, and jointly controlled in two cases. Regardless of state jurisdiction, local governments still have substantial control over siting criteria in 48 states.[72] Over half of states have some sort of wind siting criteria, whether at the state or local level, and 10 states provide local jurisdictions with voluntary guidelines in the form of model wind siting ordinances.[73] Model ordinances are not legally binding; however, portions of them may reflect policy determined at the state level that is mandatory.[74]

Noise[75,76]

States that mandate siting rules or recommend wind siting policies often provide limits on the noise levels from wind turbines that individuals living near wind energy projects may experience. In general, states with wind siting policies require or recommend that non-participating landowners are not subjected to noise levels over 55 dB(A)[77] at an occupied

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[72] Environmental Law Institute 2013

[73] Stanton 2012

[74] For instance noise limits or maximum imposed setback distances.

[75] See the "Wind-health Review" section of this report for a discussion of the potential adverse health effects elicited by noise from wind turbines.

[76] PSC 128 imposes a 50/45 dB(A) day/night limit.

[77] Median 55 dB(A), Range 45-60 dB(A).

dwelling. Some states that are more restrictive also have noise limits at property boundaries, separate day and night noise restrictions or differentials to ambient sound levels.

The NARUC report has a few key recommendations on noise restrictions. First, it recommends that noise standards should be based on land use.[78] The report argues that doing so would incorporate background noise when considering siting, as the noise levels that may elicit annoyance may be washed out to some degree by background noise and thus not be as noticeable. Second, it recommends that a clear monitoring, arbitration, and mitigation process be implemented to deal with resident complaints. Finally, it recommends using a 40 dB(A) noise level as an ideal design goal with a 45 dB(A) regulatory limit at non-participating residences. This maximum regulatory limit on noise in Wisconsin is less restrictive than this recommendation, however Wisconsin's limit is more restrictive than limits imposed by some other state and local jurisdictions.[79] Although both King and Mahon (2011) and the NARUC report recommend considering background noise, the majority of states establish absolute limits and do not formally take background noise into account as part of noise standards[80]. There is also evidence that regulations that do consider background noise or predicted noise attenuation caused by the walls of homes may not accurately reflect actual noise propagation, especially for low frequency noise.[81]

Turbine Setbacks[82]

For those states that mandate wind siting rules or recommend siting criteria, the setback distance of wind turbines from property boundaries, occupied dwellings, or public/utility rights-of-way ranges from one to five times turbine height. However, most states with wind siting rules or model ordinances recommend setback distances between one and 1.5 times turbine height, and some setback distances are contingent on turbine capacity or the type of structure or boundary to which the setback is applied.[83] Watson et al. (2012) point out that there is no perfect setback distance because local landscapes vary and there can be competing interests between wind developers and local populations.

The NARUC report takes a somewhat different stance. Rather than regulating for specific setback distances, the report recommends regulating for issues that are often reported near wind energy systems. It recommends having setbacks that would meet noise and shadow flicker

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[78] This recommendation is supported by the conclusions reached by King and Mahon 2011.

[79] For instance Colorado has 55 dB(A) day and 50 dB(A) night noise limits and the median limit imposed at 21 wind energy facilities that are under local jurisdiction throughout Michigan is 55 dB(A), with a range from 40 to 60 dB(A).

[80] Delaware, Massachusetts, Michigan and Oregon have noise restrictions that specify allowances over the ambient noise levels.

[81] Hansen et al. 2012

[82] PSC 128 allows local governments to impose a setback of 1,250 foot or 3.1 times turbine height from nonparticipating residences and occupied community buildings, and 1.1 times turbine height from property lines and public and utility rights-of-way.

[83] See Appendix G for a list of all states' policies.

restrictions, arguing that avoiding actual impacts on residents is of primary importance, rather than imposing what may be an arbitrary distance.

Shadow Flicker[84,85]

Few states offer guidelines or recommendations for shadow flicker limitations. Among those that do, limits up to 30 hours per year are common. Some other states recommend having wind developers describe the mitigation measures that they would implement to reduce the effect of shadow flicker on residences. Technology may be available that can assist in modifying turbine operations to mitigate shadow flicker impacts to residences, although it is in the early stages of deployment.[86] The NARUC report has similar recommendations to those put forward by states, and suggests shadow flicker limits of less than or equal to 30 hours of exposure per year and 30 minutes per day at non-participating residences.[87]

Decommissioning[88]

The NARUC report recommends establishing clear triggers for decommissioning,[89] in addition to requiring wind energy system owners to have an escrow account to cover decommissioning costs. States with decommissioning rules or recommendations generally call for a decommissioning plan to be submitted prior to construction, and some also suggest having proof of financial security from a turbine owner. However, the specific amount of financial security to maintain can be difficult to assess as no major wind energy systems have been decommissioned to date and the estimated cost to decommission a single turbine ranges from $9,791 to $631,875.[90]

Signal Interference[91]

Few states have policies regarding regulation of or recommended mitigation for signal interference caused by wind turbines. Those that do suggest mitigation of interference at cost to

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[84] PSC 128 allows local governments to impose a 30 hour annual limit at non-participating residences.

[85] Under PSC 128, the PSCW has the ability to create measurement, compliance, and testing protocols, including a shadow flicker compliance and mitigation protocol, but to date no shadow flicker protocol has been created. The PSCW has established a noise protocol and a stray voltage protocol.

[86] For example, turbine producer Vestas advertises the Vestas Shadow Detection System (VSDS) as able to pause turbine blades if the unit registers shadow flicker beyond a certain threshold by combining sensors with shadow modeling software.

[87] PSC 128 does not limit per day exposure.

[88] PSC 128 requires decommissioning at the end of a turbine's useful life, creates rebuttable presumptions to establish when the end of the useful life has occurred, and requires a wind energy system owner to maintain proof of financial ability to fund decommissioning.

[89] For example, operational dormancy periods after which a wind turbine owner would be required to decommission it.

[90] Ferrell and DuVuyst 2013

[91] PSC 128 allows local governments to require mitigation of any radio, television or other communications signal interference resulting from wind energy systems by its owner.

the wind energy system owner. This is consistent with the recommendations of the NARUC report. Unlike other states, Michigan's model ordinance does not permit any signal interference.

<u>Other Pertinent Findings</u>

Permitting Process

The NARUC report offers a number of insights on states' role in wind development projects. It recommends establishing a single-stop consultation process between applicants, regulators, and governmental bodies where all aspects of the project and the regulatory process can be discussed.[92] It suggests that states should also develop clear and consistent guidelines for applicants to use which should be readily available to allow for successful project development.[93] Complicated and multi-level review processes should be avoided as they have led to permitting taking over five years in other countries.[94] During this consultation and permitting process, the NARUC report calls for developing a clear, explicit, and transparent complaint review process that explicitly defines protocols for noise monitoring and mitigation.[95], [96] Finally, the NARUC report recommends that states develop maps of preferred wind energy development zones based on wind resources and land use planning and wind energy exclusion zones based on natural and other resources.[97]

Population Density

The recommendations put forward by the NARUC report are influenced by the practices utilized by states where there are fewer perceived conflicts with wind system development. The report recognizes that the "progress in wind energy development can reflect simply an abundance of wide-open spaces where turbines can be placed without affecting many citizens at all[98]", which may indicate that in considering relevant siting policy recommendations, a consideration of comparative population densities may also be useful. Appendix L provides a comparison of county and town population densities for states in the Upper Midwest where there are developed

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[92] PSC 128 requires pre-application consultation meetings, which can provide an opportunity for an applicant and the local government to discuss concerns and clarify expectations.

[93] PSC 128 requires the PSC to establish detailed Application Filing Requirements for projects permitted under PSC 128, and these Requirements are available on the PSC's website.

[94] Iglesias et al. 2011

[95] PSC 128 establishes a complaint process for complaints about projects permitted under PSC 128. The process includes the ability to appeal a decision by the local government to the PSC.

[96] PSC 128 allows local governments to use the Noise Measurement Protocol established and periodically revised by the PSC. The Noise Measurement Protocol is available on the PSC's website.

[97] Some states, including Texas, Colorado, Utah, Michigan, and Nevada provide preferred wind energy zones and others, including Wisconsin, Ohio, and Michigan, provide recommended commercial wind energy exclusion zones. See Appendix I for a map of areas not recommended for wind development established by the Wisconsin Department of Natural Resources.

[98] Stanton 2012

wind energy systems. It shows higher county and township population density in areas where wind energy systems have been developed in Wisconsin than in our neighboring states.

Property Impacts

The question of whether wind turbines impact neighboring property values was discussed by the Council in 2010 and continues to be a topic of interest in the wind siting arena. To date, no state has specifically established a regulation regarding potential property value impacts from wind turbines. However, some jurisdictions are requiring property value guarantees when issuing a permit for a wind energy development (see Appendix H).

Conclusion

Wisconsin's siting regulations for wind energy systems are evidently consistent with other state and national policy regulatory developments. It is clear that in future projects, Wisconsin should continue to provide a transparent regulatory and approval process for wind developers, as well as keep in mind that best practices should be determined by the best available information about the relationship between wind energy systems and siting and zoning.[99]

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[99] Stanton 2012

Appendix A

Wind Siting Council Membership

Wisconsin Stat. § 15.797(1)(b) requires the Commission to appoint a Wind Siting Council. Specifically, the Legislature set forth the following representation on the Council:

- Two members representing wind energy system developers (Developer Members).
- One member representing towns (Towns Member) and one member representing counties (County Member).
- Two members representing the energy industry (Energy Members).
- Two members representing environmental groups (Environmental Members).
- Two members representing realtors (Realtor Members).
- Two members who are landowners living adjacent to or in the vicinity of a wind energy system and who have not received compensation by or behalf of owners, operators, or developers of wind energy systems (Landowner Members).
- Two public members (Public Members).
- One member who is a University of Wisconsin System faculty member with expertise regarding the health impacts of wind energy systems (UW Faculty Member).

Consistent with the Legislature's directive, the Commission appointed people of diverse backgrounds and experiences, satisfying the explicit legislative statutory criteria. At the time of this report, the following individuals are members of the Council[100]:

- Bill Rakocy, Emerging Energies of Wisconsin, LLC—Developer Member
- Wes Slaymaker, WES Engineering—Developer Member (Appointed 08/29/14)
- Glen Schwalbach, Town of Rockland—Towns Member
- Scott Godfrey, Iowa County—County Member
- Andy Hesselbach, We Energies—Energy Member
- Deb Erwin, Northern States Power Company Wisconsin—Energy Member
- Michael Vickerman, RENEW Wisconsin—Environmental Member
- Tyson Cook, Clean Wisconsin—Environmental Member
- Tim Roehl—Realtor Member (Appointed 08/29/2014)
- Tom Meyer, Restraino & Associates—Realtor Member
- Jarred Searls—Landowner Member
- James Amstadt—Landowner Member
- Carl Kuehne—Public Member
- Mary Brandt—Public Member (Appointed 08/29/2014)
- Vacant—UW Faculty Member

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[100] Three members were appointed at the end of August and after the Health Section of this report had been finalized. They are noted as appointed 08/29/2014.

Appendix B

Peer Review

Peer review is an integral part of the scientific publication process. It both provides review of the hypotheses, techniques, and conclusions of scientific literature as well as support that a publication has met the standards of the scientific and technical community.[101] Peer review typically involves review of a draft manuscript by at least two independent individuals and a journal editor.

Reviewing generally adheres to the following rules:[102]

- Peer reviewers must:
    - Have expertise in the given field.
    - Be independent of the agency/research group under review.
    - Be free of real or perceived conflict of interest.
- Peer reviewers must comment on science and not policy.
- Peer reviewers must offer independent reviews of the material.

Reviewers provide comments on the writing, hypotheses, techniques, results, and validity of the conclusions reached in the manuscript. These comments are typically then reviewed by an editor to determine if the manuscript has relevance and merit for a given scientific or technical journal. If the manuscript requires clarification or reinterpretation, it is returned to the author(s) to make changes which are then evaluated by the editor to determine if the manuscript is suitable for publication.

Although this is the “gold standard” reviewing process used by scientific and technical journals, other types of review also exist that do not provide the same level of scrutiny. For instance, summary abstracts or papers that are presented at scientific or technical conferences may be reviewed by a board of editors. There are several primary differences between this type of review and the former described.

Editors of material for conferences typically:

- Review material for the interest that it will elicit as presented material.
- Are not multiple independent reviewers.
- Do not place the material under the same level of scientific scrutiny as in the journal article review process.
- Do not require a response by the author(s).
- Do not necessarily hold expertise in the field of study.

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[101] United States Office of Information and Regulatory Affairs 2004.

[102] American Association for the Advancement of Science 2005.

Although conference abstracts or papers may be published as part of a conference, these articles do not, generally, carry the same degree of scientific influence as those published in traditional scientific and technical journals for these reasons.

It should also be noted that the validity afforded to peer-reviewed literature is only as good as the process that was used for the review. If non-experts are consulted or if experts review materials outside of their field of study, then material has *not* been adequately academically peer-reviewed. Although high-impact[103] journals place a strong emphasis on the review process and are highly selective in materials they publish, low impact journals may not subject their manuscripts to the same level of scrutiny. This may occur for three primary reasons: 1) low-impact journals generally receive fewer manuscripts than high-impact journals, and thus inherently are not able to be as selective in choosing manuscripts to publish, 2) low-impact journals generally receive manuscripts from inexperienced researchers (e.g., a summer study by an undergraduate research assistant) which may be more technically flawed than manuscripts prepared by senior scientists, and 3) expert reviewers are often less inclined to review manuscripts for low-impact journals as the review process is voluntary, reviewers have limited time, and reviewing for a low-impact journal does not add the same level of prestige to the reviewers' career as reviewing manuscripts for a high-impact journal. This is not to say that valid scientific research is not published in low-impact journals, however caution may be warranted when interpreting low-impact publications.

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[103] "Impact factor" is a calculation based the number of times a journal is cited over the total number of all citations in a given time period and is a proxy for importance. High-impact journals carry more weight, prestige, and influence than low-impact journals and include journals such as *Science, Nature,* and *The New England Journal of Medicine*.

Scientific Documents

There are several types of scientific and technical publications, all of which carry different levels of scientific purpose, scope, scrutiny, and influence. These are general descriptions and do not represent any and all cases. Footnotes indicate examples of each that are available in the relevant wind-health literature.

Type	Scope	Peer-reviewed?	Influence	Description
Articles	Research[104]	Yes	High	Presents the results of an original study that has been vetted to ensure that it complies with accepted scientific standards, including study design, sampling techniques, and statistical methods.
Articles	Meta-analysis	Yes	High	Presents the summarized, analyzed results of multiple research articles. Both the articles used for the analysis and the meta-analysis itself have been vetted to ensure they comply with accepted scientific standards, including study design, sampling techniques, and statistical methods.
Articles	Review[105]	Yes	High	Presents a summary of multiple research articles and meta-analyses. Both the articles used for the review and the review itself have been vetted to ensure they comply with accepted scientific standards.
Articles	Opinion[106]	Yes	Moderate	Presents the opinions of the author(s) on a scientific topic. The opinion has been vetted as reasonable, informative, and advancing from a scientific or technical viewpoint.

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[104] Pawlaczyk-Luszczynska et al. 2005
[105] Bastasch et al. 2006
[106] Bronzaf 2011

Type	Scope	Peer-reviewed?	Influence	Description
Major Governmental or Non-governmental Organization	Research	No	High	Presents the results of an original study that has been conducted by appointed experts. Although these types of studies are not necessarily vetted, the researchers are generally considered to be leaders in their field and therefore conformists with scientific standards. Publications directed by major governmental agencies (e.g., state, federal, or international agency) or non-governmental organizations (e.g., World Health Organization) are generally considered to hold similar validity as top research articles.
Major Governmental or Non-governmental Organization	Review[107]	No	High	Presents a review of research articles and meta-analyses conducted by appointed experts. Although these types of reviews are not necessarily vetted, the researchers are generally considered to be leaders in their fields and therefore conformists with scientific standards. Publications directed by major governmental agencies (e.g., state, federal, or international agency) or non-governmental organizations (e.g., World Health Organization) are generally considered to hold similar validity as top review articles.

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[107] Ellenbogen et al. 2012

Type	Scope	Peer-reviewed?	Influence	Description
Major Governmental or Non-governmental Organization	Guidelines[108]	No	High	Presents recommendations on a given subject based on the knowledge and experience of appointed experts. Although guidelines are not necessarily vetted, the writers are generally considered to be leaders in their fields and therefore conformists with scientific standards. Guidelines recommended by major governmental agencies (e.g., state, federal, or international agency) or non-governmental organizations (e.g., World Health Organization) are generally considered as balanced and based on relevant scientific evidence.
Reports	Report[109]	No	Limited	Presents the results of observations, often by a scientific or technical consulting firm. The report procedural design generally complies with accepted sampling techniques, however it generally does not represent a broad sampling, the results of which could be statistically applied over other geographic areas or situations.
Self-published material, Websites, Blogs, etc.	Any	No	Limited	Presents the views of experts or non-experts. These views are of varying degree of validity, review, and may or may not be reliable or attributable.

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[108] World Health Organization 2009

[109] Walker et al. 2012

Appendix C

Summary of Governmental Reports

The Council identified three governmental reports reviewing the effect of wind energy facilities on human health and well-being.[110] All of these reports serve a similar function to this report in that they were designed to survey the pertinent wind-health literature and provide policy recommendations. Although these reports are not peer-reviewed, they are generally prepared by panels of experts[111] for governmental bodies and hold similar weight as top peer-reviewed publications.

National Health Service, Shetland, Scotland

The National Health Service, Shetland, Scotland recently released its "Report on the Health Impacts of Wind Farms Shetland 2013" (Shetland report).[112] The author's goal in this report was "to provide a report on the 'health effects (if any) of wind farms'" and the health issues examined included construction, operation, and maintenance safety, shadow flicker, EMF, and noise.

The author of the Shetland report concluded that there is not a significant health risk to individuals living near wind turbines during construction or operation of wind energy systems. However, there is risk to construction workers, on the scale of any other large construction project. Unlike other governmental reviews and the general scientific consensus, the Shetland report concluded that utility-scale wind turbines may pose a seizure risk to photosensitive epileptics due to the shadow flicker that is produced by turbine operation. It was noted, however, that this is only an issue during abnormal operational speeds. EMF was also briefly discussed in this wind-health report. The author concluded that there is no risk to individuals living near wind turbines from EMF.

Similar to many of the findings discussed previously, the Shetland report concluded that wind turbines do produce noise that is annoying to some people. The report indicated that distance to wind turbines is directly related to reports of annoyance and that other factors, such as turbine visibility and economic gain, also influence annoyance. Wind turbines may also interrupt sleep in some individuals living near them. The report concludes that annoyance and sleep deprivation may interact to increase stress and lead to, indirectly, some chronic health conditions. The Shetland report notes that ILFN may be annoying to some people, however the levels produced by wind turbines are generally less than from other industrial noise sources and are likely inaudible to most people. The author states that some caution should be taken in these

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[110] Ellenbogen et al. 2012, Joshi et al. 2013, Taylor 2013. The Council identified two additional governmental reports regarding ILFN.

[111] With the exception of Taylor 2013, which was prepared by one expert.

[112] Taylor 2013

conclusions, however, because of the "limited amount of original scientific research" on these topics available at the time.

Oregon Office of Environmental Health

Also in 2013, the Oregon Office of Environmental Health, Public Health Division released the final draft of its "Strategic Health Impact Assessment on Wind Energy Development in Oregon".[113] The objective of this exhaustive review was to provide a document to "assist stakeholders to understand and respond to health-related questions at new wind energy developments […]." Towards this end, the panel reviewed the effects of wind energy facilities on sound, visual impacts, and air pollution, among other things.

Oregon's key findings on the impacts of wind turbine noise on human health are similar to those described in the Shetland report. This assessment found that wind turbines produce noise that may be unwanted and annoying, which may lead to stress. Wind turbine noise may be more annoying relative to other noise sources due to its rhythmic nature. However other effects also influence annoyance such as subjective experience, distance to wind turbines, and whether an individual benefits financially from the turbine. Oregon's assessment also found that wind turbines produce ILFN at levels below human hearing, but that at some locations it approaches levels that may be perceived by humans. It concluded that long term exposure to sound levels of a high enough level may impact peoples' health, however uncertainty on the effects of turbines exists "due to moderate or limited evidence […]."

When considering shadow flicker, Oregon concluded that it is unlikely to cause adverse health effects or trigger seizures in epileptics and that few individuals will be annoyed by it. The Oregon assessment also found benign local effects in air pollution associated with the construction of turbines, with any emissions produced by construction having local and short-term impacts. Overall, the Oregon assessment concludes that adoption of wind energy reduces pollution-caused adverse health effects associated with fossil fuel power generation and will help alleviate future climate change.

Massachusetts Departments of Environmental Protection and Public Health

The Massachusetts Departments of Environmental Protection and Public Health commissioned an expert panel to do an independent review of potential health impacts of wind turbines in 2012.[114] The goal of the expert panel was to "identify any documented or potential health impacts or risks that may be associated with exposure to wind turbines […]." Specifically, the panel was charged with reviewing existing data and literature to evaluate the effects of wind turbine noise, vibration, and shadow flicker on human health, among other things. This review came to similar conclusions as the Shetland and Oregon reviews, and this Council's survey of the literature. It found that there is limited evidence that wind turbines can cause annoyance and

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[113] Joshi et al. 2013
[114] Ellenbogen et al. 2012

sleep disruption and concludes that it is very difficult to decouple the effects of interpersonal views on wind turbines from perceived annoyance. The Massachusetts panel also concluded that infrasound produced by wind turbines is below the audible threshold of humans, that the possibility that infrasound from wind turbines is able to stimulate the vestibular systems (outer hair cell pathway) has not been sufficiently scientifically explored, and that the limited epidemiological evidence does not suggest that wind turbines are responsible for chronic adverse health effects. Finally, the panel concluded that shadow flicker does not elicit seizures, but may cause annoyance if individuals are exposed for a sufficient duration.

Appendix D

Works Cited

Author	Title	Journal	Year	Volume	Edition	Pages	Type
Ambrose SE, Rand RW, Krogh CME	Wind turbine acoustic investigation - infrasound and low-frequency noise - a case study	Bulletin of Science, Technology & Society	2012	32	2	128-141	Article, Opinion
American Association for the Advancement of Science	AAAS Policy Brief: OMB Bulletin on Peer Review		2005				Report, Guidelines
Arra I, Lynn H, Barker K, Ogbuneke C, Regalado S	Systematic review 2013: Association between wind turbines and human distress	Cureus	2014			1-15	Article, Review
Bakker RH, Pedersen E, van den Berg GP, Stewart RE, Lok W, Bouma J	Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress	Science of the Total Environment	2012	425	1	42-51	Article, Research
Bastasch M, van Dam J, Sondergaard B, Rogers A	Wind turbine noise – An overview	Canadian Acoustics	2006	34		7-15	Article, Review
Bolin K, Bluhm G, Eriksson G, Nilsson ME	Infrasound and low frequency noise from wind turbines - exposure and health effects	Environmental Research Letters	2011	6	3	1-6	Article, Research
Bronzaft AL	The noise from wind turbines: Potential adverse impacts on children's well-being	Bulletin of Science, Technology & Society	2011	31	4	291-295	Article, Opinion
Chapman S, St. George A, Waller K, Cakic V	Spatio-temporal differences in the history of health and noise complaints about Australian wind farms: Evidence for the psychogenic , “communicated disease” hypothesis	PLos One	2013	8	10	1-11	Article, Research

Author	Title	Journal	Year	Volume	Edition	Pages	Type
Crichton F, Dodd G, Schmid G, Gamble G, Cundy T, Petrie KJ	The power of positive and negative expectations to influence reported symptoms and mood during exposure to wind farm sound	Health Psychology	2013b			1-5	Article, Research
Crichton F, Dodd G, Schmid G, Gamble G, Petrie KJ	Can expectations produce symptoms from infrasound associated with wind turbines?	Health Psychology	2013a	32			Article, Research
Ellenbogen JM, Grace S, Heiger-Berays WJ, Manwell JF, Mills DA, Sullivan KA, Weisskopf MG	Wind turbine health impact study: Report of independent expert panel		2012				Report, Review
Environmental Law Institute	Siting wind energy facilities - What do local elected officials need to know?		2013				Report, Guidelines
Farboud A, Crunkhorn R, Trinidade A	"Wind turbine syndrome": Fact or fiction?	The Journal of Laryngology and Otology	2013	127	3	222-226	Article, Review
Fargione J, Kiesecker J, Slaats MJ, Olimb S	Wind and wildlife in the Northern Great Plains: Identifying low-impact areas for wind development	PloS One	2012	7	7	1-14	Article, Research
Ferrell SL, DeVuyst EA	Decommissioning wind energy projects: An economic and political analysis	Energy Policy	2013	53		105-113	Article, Opinion
Fiumicelli D	Wind farm noise dose response: A literature review	Acoustics Bulletin	2011	11/12		26-34	Article, Review
Hanning CD, Evans A	Wind turbine noise: Seems to affect health adversely and an independent review of evidence is needed	British Medical Journal	2012	344	e1527	1-3	Article, Opinion
Hansen K, Henrys N, Hansen C, Doolan C, Moreau D	Wind farm noise – What is a reasonable limit in rural areas?	Proceedings of Acoustics	2012	Nov	21-21	1-8	Article, Research
Harrison JP	Wind turbine noise	Bulletin of Science, Technology & Society	2011	31	4	256-261	Article, Opinion

Author	Title	Journal	Year	Volume	Edition	Pages	Type
Havas M, Colling D	Wind turbines make waves: Why some residents near wind turbines become ill	Bulletin of Science, Technology & Society	2011	31	5	414-426	Article, Opinion
Horner B, Jeffery RD, Krogh CME	Literature reviews on wind turbines and health: Are they enough?	Bulletin of Science, Technology & Society	2011	31	5	399-413	Article, Review
James RR	Wind turbine infra and low-frequency sound: Warnings signs that were not heard	Bulletin of Science, Technology & Society	2011	32	2	108-127	Article, Opinion
Janssen SA, Vos H, Eisses AR, Pedersen E	A comparison between exposure-response relationships for wind turbine annoyance and annoyance due to other noise sources	Journal of the Acoustical Society of America	2011	130	6	3746-3753	Article, Research
Jeffery RD, Krogh C, Horner B	Adverse health effects of industrial wind turbines	Canadian Family Physician	2013	59	1	473-475	Article, Opinion
Joshi S, Hamberg A, Cain D, Douglas JP, Teshale S, Early-Alberts J	Strategic health impact assessment on wind energy development in Oregon		2013				Report, Review
Kaldellis JK, Garakis K, Kapsali M	Noise impact assessment on the basis of onsite acoustic noise emission measurements for a representative wind farm	Renewable Energy	2012	41	1	306-314	Article, Opinion
Katsaprakakis DA	A review of the environmental and human impacts from wind parks. A case study for the Prefecture of Lasithi, Crete	Renewable and Sustainable Energy Reviews	2012	16	6	2850-2863	Article, Research
King EA, Pilla F, Mahon J	Assessing noise from wind farm developments in Ireland: A consideration of critical wind speeds and turbine choice	Energy Policy	2012	41		548-560	Article, Research
Knopper LD, Ollson CA	Health effects of wind turbines - A review of the literature	Environmental Health	2011	10	78	1-10	Article, Review
Krogh CME	Industrial wind turbine development and loss of social justice?	Bulletin of Science, Technology & Society	2011	31	4	321-333	Article, Review
Krogh CME, Gillis L, Kouwen N, Aramini J	WindVOICE, a self-reporting survey: Adverse health effects, industrial wind turbines, and the need for vigilance monitoring	Bulletin of Science, Technology & Society	2011	31	4	334-345	Article, Research
McMurtry RY	Toward a case definition of adverse health effects in the environs of industrial wind turbines: Facilitating a clinical diagnosis	Bulletin of Science, Technology & Society	2011	31	4	316-320	Article, Opinion

Author	Title	Journal	Year	Volume	Edition	Pages	Type
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Mulvaney KK, Woodson P, Prokopy LS	A tale of three counties: Understanding wind development in rural Midwestern United States	Energy Policy	2013	56		322-330	Article, Research
Nissenbaum MA, Aramini JJ, Hanning CD	Effects of industrial wind turbine noise on sleep and health	Noise & Health	2012	14	60	237-243	Article, Research
Office of Information and Regulatory Affairs	Final Information Quality Bulletin for Peer Review		2004				Report, Guidelines
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Pedersen E	Health aspects associated with wind turbine noise - Results from three field studies	Noise Control Engineering Journal	2011	59	1	47-53	Article, Research
Phillips CV	Properly interpreting the epidemiological evidence about the health effects of industrial wind turbines on nearby residents	Bulletin of Science, Technology & Society	2011	31	4	303-315	Article, Opinion
Rand RW, Ambrose SE, Krogh CME	Occupational health and industrial wind turbines: A case study	Bulletin of Science, Technology & Society	2011	31	5	359-362	Article, Research
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Stanton T	Wind energy & wind-park siting and zoning best practices and guidance for states		2012				Report, Guidelines
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Taylor S	Report on the health impacts of wind farms, Shetland 2013		2013			1-52	Article, Review
Thorne B	The problems with "Noise Numbers" for wind farm noise assessment	Bulletin of Science, Technology & Society	2011	31	4	262-290	Article, Research
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Vanderburg WH	Assessing our ability to design and plan Green Energy Technologies	Bulletin of Science, Technology & Society	2011	31	4	251-255	Article, Opinion
Walker B, Hessler GF, Hessler DM, Rand R, Schomer P	A cooperative measurement survey and analysis of low frequency and infrasound at the Shirley Wind Farm in Brown County, Wisconsin		2012			1-51	Report, Research

Author	Title	Journal	Year	Volume	Edition	Pages	Type
Watson I, Betts S, Rapaport E	Determining appropriate wind turbine setback distances: Perspectives from municipal planners in the Canadian provinces of Nova Scotia, Ontario, and Quebec	Energy Policy	2012	41		782-789	Article, Opinion
World Health Organization	Night noise guidelines for Europe		2009				Report, Guidelines

Appendix E

Minority Analysis prepared by Tyson Cook, Bill Rakocy, and Michael Vickerman

Introduction

The Wind Siting Council has an important and valuable role in providing advice and counsel around the development of wind siting regulations in the State of Wisconsin. We acknowledge that there are a large number of stakeholders affected by regulations and any regulatory developments, and consequentially there will be a broad array of opinions on various relevant issues. Appropriately, the Wind Siting Council is comprised of members representing a broad range of stakeholders and opinions.

Despite differences of opinion between stakeholders and Wind Siting Council members, the Council has been able to work effectively together over many months in a collaborative manner, and to come to broad consensus on a number of topics. On other topics where consensus could not be reached, the Council has generally been successful in working to reach agreement between significant majorities of the members. As should be expected however, there are still some topics where opinions are strongly held by a minority of Council members. In order to allow these opinions to be clearly stated, the Council has agreed to permit the attachment of "Minority Reports" to the Wind Siting Council report (hereafter "Report"). This Minority Report addresses the disagreement among Council members regarding the scope of health impacts of wind energy systems to be considered.

Charge of the Wind Siting Council

As noted in the Report, the Wind Siting Council acts under certain statutory obligations. In particular, Wis. Stat. 196.378(4g)(e) requires that:

> "The wind siting council shall survey the peer-reviewed scientific research regarding the health impacts of wind energy systems and study state and national regulatory developments regarding the siting of wind energy systems…"

We find that the Council has done an excellent job, in keeping with these obligations, of reviewing the available peer-reviewed research regarding the potential for direct negative health impacts of large wind energy systems to residents living near those systems. We further believe that the assessment and overall conclusion of the Wind Siting Council based on that review is sound, namely the finding that:

> "Although there are several publications arguing that noise from wind turbines directly causes adverse health effects in humans, based upon the peer-reviewed literature, it appears at this time that there is insufficient data to validate this scientific conclusion."

However, while there is some latitude for interpretation of the charge under Wis. Stat. 196.378(4g)(e), there is no basis for limiting the Report to the examination of potential negative direct health impacts to residents living next to those systems as was decided by the Council during the open meeting of 4/7/2014. Indeed, we believe that the statutory language calling for a survey of peer-reviewed literature creates an obligation to include literature which also addresses positive health impacts on the vast majority of Wisconsin's population that does not live next to wind turbines. This obligation requires the Wind Siting Council to include any peer-reviewed studies regarding health benefits from reduced fossil fuel emissions that result from increased wind energy generation.

The importance of considering these broader public health impacts in the Report is significant. The specific wind siting decisions that are made pursuant to state rules and regulations can have varying levels of health benefits at the regional scale. The nature of electrical system operation is such that generation is dispatched based in part on locational need. The specific location of wind energy systems thereby affects the types of generation displaced and therefore the corresponding levels of health benefits. Additionally, the siting of wind energy systems in locations that reduce transmission congestion can also magnify health benefits by reducing electrical losses in transmission lines. The rules and regulations that govern the siting of wind energy systems also impact the amount of health benefits that may accrue on the statewide level, by affecting the ability for those systems to be installed in the state.

Public Health Impacts of Wind Energy Systems

In neglecting to include the full range of research on "health impacts of wind energy systems," the Report does not represent a complete survey of the relevant peer-reviewed scientific literature the Wind Siting Council is charged with. Instead, the report as drafted could best be described as an examination of writings regarding reported health complaints of individuals living near wind farms. As such, it does not provide the level of understanding on the issue at hand that would be necessary to make informed decisions. Indeed, by excluding recent peer-reviewed research on broader public health impacts - which may be qualitatively at odds with some of the other potential impacts examined - the report exhibits a level of observational bias that may lead to inaccurate conclusions in the minds of readers and fails to fulfill the Wind Siting Council's statutory requirements in Wis. Stat. 196.378(4g)(e).

In addition to the growing body of scientific evidence refuting a direct linkage between wind turbines and negative, localized health impacts through mechanisms such as infrasound and low frequency noise, there is a large and long-standing consensus around other issues relevant to the health impacts of wind energy systems to the public. Most significant of these are the avoided emissions that would result as wind energy systems displace the combustion of fossil fuels to generate electricity. Through the avoidance of these fossil fuel emissions, wind energy systems directly increase our air quality and benefit public health and welfare.

These public health impacts were recently examined by Greene and Morrissey (2013), who studied the accrual of health benefits associated with wind energy production the producing state.

The research focused on sulfur dioxide (SO_2) and nitrous oxide (NO_x) emissions, since the effects of those pollutants are more localized geographically and temporally. The authors found that the displacement of electricity production from fossil fuel sources resulted in significant local health benefits, consistent with other research.[115] In particular, their research estimated that emissions avoided due to wind energy systems in Oklahoma resulted in over 1,000 fewer premature deaths for 2011, along with an additional reduction of over 1,000 non-fatal heart attacks, 2,000 hospital visits, 500 cases of chronic bronchitis, and 90,000 work and school absences due to illness. The authors note that the reductions in SO_2 and NO_X emissions, which were also seen by Madaeni and Sioshansi (2012) in Texas, "clearly illustrate the health benefits brought on by the increased use of wind energy in Oklahoma," and that on an economic basis "these values represent a savings of tens of millions of dollars annually."

In a systematic assessment of renewable energy across the United States, Siler-Evans et al. (2013) also examined the health benefits resulting from emission reductions as a result of wind energy, specifically displaced carbon dioxide (CO_2), SO_2, NOx, and fine particulate matter (PM2.5). The assessment estimated the potential avoidance of emissions and the related health and environmental impacts from a hypothetical wind energy system sited at any one of 33,000 locations across the United States. The avoided impacts were based on analysis of the "marginal electricity production" at each of those locations, which is the electricity generation that would be displaced by the installation of the wind energy system in that particular site. In conducting the assessment, the authors used economic values of health and environmental damages for each hour from 2009 through 2011, quantified using dollar-per-ton damages from over 1,400 fossil-fueled power plants.

The results showed that the displacement of pollutants resulted in varying amounts of avoided cost, depending on location and generation mix. More coal-reliant states were shown to have higher health and environmental benefits associated with wind energy systems than states which utilize more natural gas or renewable energy. For instance it was noted that, "a wind turbine in West Virginia avoids $230 in health and environmental damages per kilowatt per year ($81/MWh) - seven times more than a wind turbine in Oklahoma and 33 times more than a wind turbine in California." It should be noted that the $81/MWh estimated on the high end by Siler-Evans et al. is within or below the range estimated by others for external health costs from emissions of coal-fired power plants. For example, Smith et al. (2013) estimate those costs to be between $32/MWh and $289/MWh, while Machol and Rizk (2012) estimate $140-450/MWh. Both of those studies also reinforce the importance of location and generation mix to the total value of emissions avoided, with coal-reliant states such as Wisconsin seeing the greatest benefit.

Research done by McCubbin and Sovacool (2013) directly compared two wind farms, Altamont (580MW) and Sawtooth (22MW), to electricity production through natural gas. Since natural gas production is the fossil fuel with fewest health impacts related to pollutant emissions, this provides a very conservative estimate for the positive public health impacts associated with wind energy systems. Like Siler-Evans et al. (2013), McCubbin and Sovacool (2013) use models to

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[115] See, e.g. Liu et al. (2012) who found "a significant elevation of hospitalization for respiratory diseases among individuals… who lived near a fuel-fired power plant."

evaluate the economic costs of health and environmental impacts such as increased morbidity and mortality from air pollution and incidence of noise and reduced amenity, aesthetics and visibility, which are seen from the respective generation sources. The study featured a particular focus on PM2.5, due to the health issues it creates. The authors used the Co-Benefits Risk Assessment Tool (COBRA) to model how emissions affect ambient PM2.5 levels. They take the avoided emissions and convert them into economic values based on estimated social costs and valuation of public health endpoints, such as hospital admissions and work loss days. The results were that between 2012 – 2031, the Altamont site would result in an estimated $560 million to $4.38 billion in public health and environmental benefits, and the Sawtooth site would result in estimated benefits of $18 million to $104 million. These numbers were again consistent with the estimates of other researchers regarding the value of avoided emissions, such as Smith et al. (2013) and Machol and Rizk (2012). However, a state with a larger portion of coal-powered electricity generation like Wisconsin could be expected to have larger public health benefits than the California electrical generation system considered by McCubbin and Sovacool (2013), which is comprised of less than 1% coal generation.

Based on the $0.20/kWh value from Machol and Rizk (2012), a 580MW project like that considered by McCubbin and Sovacool (2013) could result in approximately $300 million in benefits annually, or $5.4 billion over a similar time period (2012-2031) in the state of Wisconsin.

International research has also examined the link between wind energy systems and public health impacts. For instance, both Partridge and Gamkhar (2011) and Ma et al. (2013) examine the emissions avoided in China by the addition of wind power production. Partridge and Gamkhar (2011) use the measurements from 117 wind projects, as compared to emissions data from a single 1200MW supercritical coal-power plant (similar to the Elm Road Generating Station in Wisconsin). Focusing only on PM2.5, their results show emissions reductions resulting in avoided premature deaths, avoided new cases of chronic bronchitis, and avoided hospital stays resulting from the projects. These results agree with the findings of Liu et al. (2012) who saw increases of 11%, 15%, and 17% respectively in hospitalization due to asthma, acute respiratory infections, and chronic obstructive pulmonary disease in individuals living near fossil-fired power plants in New York compared with those who did not. Similarly, Ma et al. (2013) studied the emissions offset by two 49.5MW wind power projects in relation to a regional data from 2001 to 2010, and found that emissions mitigation from the wind power production resulted in cost savings due to lower health care costs through improved air quality and reduced damage to public health, of over $1.38 billion (USD).

It should be noted that peer-reviewed scientific research summarized in this report represents only that which explicitly and directly links wind energy systems to human health outcomes. There is a much larger body of work that could be drawn upon to independently show both (1) the potential for pollution reductions as a result of wind energy systems, and (2) the potential benefits to human health from such reductions. Despite their relevance to the topic, those articles were not included here for the sake of brevity, due to the sheer volume of such research and because they can be safely anticipated to yield qualitatively similar findings.

The public health benefits of non-polluting renewable energy systems such as wind turbines have been one of many reasons for their installation across the nation. Indeed, even health benefits going beyond the more traditional pollutants (e.g. the fine particulate matter, sulfur dioxide, and nitrogen oxides that were the major focus of the research discussed in this Minority Report) have been well established. A recent demonstration of this is the proposed rules by the U.S. Environmental Protection Agency (EPA) to limit carbon pollution under section 111(d) of the under the federal Clean Air Act. The establishment of these rules was necessitated by a series of rulings by the U.S. Supreme Court, which upheld the finding that greenhouse gases endanger public health and placed a legal obligation on the EPA to limit such gases. In their proposed rules to limit those greenhouse gases, and thereby reduce the endangerment to public health and welfare, the EPA specifically included the use of renewable energy systems such as wind energy as a potential compliance mechanism.

Conclusion

A survey of peer-reviewed research regarding public health impacts related to wind energy systems uniformly indicates health benefits resulting from the operation of those systems. This is in stark contrast to the lack of evidence in the peer-reviewed scientific literature to substantiate the direct adverse health effects that the Council focused on in the Report. As opposed to the potential for negative effects examined by the Council, the public health benefits of reduced air pollution that result from the operation of wind energy systems are well known and widely understood.

The Wind Siting Council has an important advisory role with regard to the development of wind siting regulations in the State of Wisconsin. While the Report developed by the Council is a step toward fulfilling its statutory obligations, it does not fully meet that charge. The inclusion of peer-reviewed scientific research on the topics noted here clearly falls within the framework for the Report established under Wis. Stat. 196.378(4g)(e). Aside from statutory obligations, it is also critical that the Wind Siting Council consider these topics because the potential for health benefits from wind energy systems are directly impacted by, and are therefore directly relevant to discussions of, wind siting rules and regulations in the state.

The research discussed here demonstrates a consensus among the scientific community that there are public health benefits resulting from wind energy systems. The work and findings described by the majority Wind Siting Council report make clear that this consensus is not counter-balanced by similar scientific evidence of potentially negative direct health impacts. The sum of these two facts makes clear the following: from the perspective of scientific peer-reviewed research, wind energy systems substantially benefit human health and welfare.

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Appendix F

Wisconsin
Wind Siting Council

Minority Response

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Additionally signed onto by Mary Brandt and Tim Roehl

Wind Turbine Siting-Health Review
Wind Turbine Siting-Policy Update
and
Recommendations for Legislation

October 2014

Executive Summary

In 2009, Wisconsin Act 40 directed the Public Service Commission of Wisconsin (Commission or PSC) to appoint a Wind Siting Council (Council or WSC) to provide advice to the PSC during the rule- making process for the siting of wind turbines. Act 40 also requires that Council to submit a report to the Legislature every 5 years to provide updated information about health research and regulatory developments, as well as to provide recommendations for legislation if needed.

Act 40 specifies the makeup of the membership of the Wind Siting Council and it created a bias in the form of a majority made up of several pro-wind energy interests and pro-wind environmentalists versus a minority of others who would focus on safety and health. Because of that built-in pro-wind bias, the Council's minority created this Minority Report to reveal the information that the Council majority omitted from the Wind Siting Council report to the Legislature.

The pro-wind bias, as found on the Wind Siting Council, is found on the PSC staff as well. One reason for the PSC's bias is that it seems they deem that the statute for Renewable Portfolio Standards requires them to "go easy" on safety and health restrictions for wind energy projects. This bias has created wind siting rules in Wisconsin that are not as protective as they should be. Wisconsin's wind siting law and rules (PSC 128) require local units of government to process applications for all but the largest wind projects. These wind projects are extremely complicated and are often unique to the local land features. But local governments are not allowed to consider safety and health protections that are more restrictive than PSC 128. So, they cannot require protections to suit the local circumstances, to adopt the recommendations of their medical or technical experts or engineers, to accommodate the latest science, or to require the latest protective technologies. Wisconsin law and PSC 128 require local government units to approve these wind projects with noise restrictions and setbacks that the Council's current regulatory review would consider to be some of the least protective in the country.

This Minority Report highlights areas in PSC 128 that differ from health standards and best practices found in the documents reviewed by the Council for the Majority Report, differences that were downplayed by the pro-wind Council majority. These health standards and best practices are designed to protect non-participating homeowners' health and property rights. These best practices strike a balance between protecting residents and creating a regulatory environment that the wind industry can use to get approvals that work for both the industry and the communities where they are built.

Because Wisconsin's wind siting law is so dysfunctional, wind turbine development plans are met with great opposition by the communities where they are proposed. The communities that object are aware of the health concerns that are described in the Minority Report. Wind turbine noise is linked to chronic sleep disturbance, which is linked to more serious physical maladies. Wisconsin law does not allow setbacks that adequately prevent harmful noise impacts to homeowners. Officials are not permitted to set wind turbine setbacks any farther than an arbitrary 1250-foot or 3.1 times the total height, whichever is less, from a neighbor's occupied structure.

The Council’s regulatory review also found that, because Wisconsin’s setback is from a wind turbine to a neighbor’s occupied structure, some of that neighbor’s land is now inside the “safety setback” distance from the wind turbine. This "safety setback" can overlap as much as 800 feet of that neighbor's property. This is a “taking” of the owner’s property right to use their land for intended purposes because it is no longer possible to build with local building setbacks near their property line and stay outside of the "safety setback" due to a turbine being located nearby. In other states there is a trend to create setbacks a safe distance from the neighbor’s property line instead of the neighbor’s structure.

A significant study done by a member of the Council showed that the towns in which wind projects have been built in Wisconsin have population densities generally much higher than towns or townships in neighboring states where similar projects have been built. Couple this with the fact that the wind resource in Wisconsin is much less than in these neighboring states, and it is like forcing a square peg into a round hole, whereby there is likely to be some severe damage. Wisconsin's existing wind projects have been permitted in our more populated areas, and thus, are more often too close to residences with more resultant negative health impacts than in other states.

This Council minority concludes that Wisconsin’s wind siting law needs revision for noise protection and property rights protection. Also, a restructuring of the Wind Siting Council makeup is needed to eliminate bias, as is a restructuring of what information the Council is allowed to review in order to advise the Legislature about wind energy systems. Rewriting the wind siting laws to offer better protections for non-participating residents and correcting the bias of the Wind Sting Council will restore the public trust in the wind-siting laws of Wisconsin, creating a win-win situation for both the wind industry and non-participating residents.

To proceed wisely, the minority, the majority and numerous technical and public policy experts agree that more acoustic and epidemiological studies are needed. Wisconsin wind projects are ripe for such studies before more damage is done, but government funding is needed.

Also, Wisconsin needs a process to compensate those citizens who had to abandon their homes to get relief from negative health effects, who have not moved and suffer negative health effects, or who have taken a financial loss due to a neighboring wind project.

Please read the full Minority Report for the complete details and conclusions.

1.0 Purpose:

The purpose of this report by the Council minority is to challenge the reader to take a second look at all of the available data on the subject of wind turbine health impacts and evaluate this data in a more critical light. To ensure that the economic interests of wind turbine project developers were protected in the recommendations made to the Legislature, the Council majority opinion sided with pro-wind factions to minimize any impediments to the construction of wind turbine projects.

The Council minority consists of six (almost half) of the fourteen participants in the Wind Siting Council, including both Public Members, the Towns member, both Realtor Members, and one Landowner Member.

Ultimately, the Council majority found secondary in their report the importance of the proper siting of wind turbines and the direct impact these turbines have on the health and welfare of citizens. The Council minority opinion takes a more cautious and concerned approach to wind development, placing a priority on the siting rules of wind turbines and the health and welfare of people over the interests of wind energy developers and system operators. This Minority Report will reveal the shortcomings of Wisconsin's current statewide wind siting law under which the rules (PSC 128) were promulgated and recommend areas where the law and, thus, PSC 128 should be improved.

<u>2.0 Applicable Statutes and Limitations:</u>

2009 Wisconsin Act 40 directed the Public Service Commission of Wisconsin (Commission or PSC) under Wis. Stat. §15.797 to appoint a Wind Siting Council (Council or WSC) to provide advice and counsel to the Commission during the rule-making process for the siting of wind turbines. In addition, the Council under Wis. Stat. §196.378(4g)(e) shall report to the Legislature every five years after surveying health research and regulatory developments and shall make recommendations for legislation, if any.

Wis. Stat. §15.797(1)(b) contains statutory guidelines that favors a Council heavily weighted towards wind development. Recognizing that, in the Council's current composition, a bias exists in favor of wind energy interests and that members in the majority of the Council have made great efforts to disqualify and discredit documents linking wind turbines to negative health effects, there exists a justifiable rationale for the necessity of this Minority Report to supplement the Council majority's findings.

Further limiting the WSC's scope on reviewing the health impacts of wind turbine development is the fact that the Council majority interpreted Wis. Stat. § 196.378(4g)(e) as directing the Council to survey *only* peer-reviewed scientific research regarding the health impacts of wind energy systems and to review *only* U.S. state and national regulatory developments regarding the siting of wind energy systems. Consequently, the Council has considered only a microcosm of relevant studies and policies that by themselves do not reveal all of the factors vital to protecting human health and safety.

Although Wis. Stat. § 196.378(4g)(e) does list the type of documents that the Council must consider, we, the Council minority, do not consider that list to be exclusive of other relevant data. We find that the inclusion of other credible research, empirical evidence, and affidavits is in the best interest of the public. Inclusion of such documents will provide the Legislature and the PSC with a more complete and better representation of the effects that wind turbines have on human health.

It is the responsibility of the Legislature to address the experiential realities of citizens affected by wind turbines and it is the Council's responsibility to provide the Legislature with pertinent information that addresses all health concerns that may affect the quality of life as it relates to siting a wind turbine near residences.

3.0 Minority Review of Majority Health Summary

In its summary of *Key Findings from Wind-health Literature*, the Council recognized several trends in its review of the selected literature since the Council's 2010 recommendations. Of primary concern on the matters of health are cross-sectional surveys that show evidence of individuals living in the proximity of wind turbines experiencing elevated levels of annoyance and sleep disturbance due to wind turbine noise while the turbines are in operation. Two studies showing cause for alarm are Janssen et al. (2011) and Bakker et al. (2012) that found a staggering *40 percent and 66 percent (respectively) of individuals* studied reported to be both annoyed or highly annoyed by wind turbines producing outdoor sound levels over 45 dB(A).

It should be noted that stress from annoyance and sleep disturbance may be related to chronic health conditions and that individual perception may increase or decrease the severity of reported conditions. The long-term effects of chronic sleep restrictions and deprivation have been thoroughly studied and have been identified by the American Academy of Sleep Medicine to include symptoms of depression, anxiety, fatigue, high blood pressure, obesity, heart attack and diabetes. Coupled with these medical and mood conditions are performance reductions including attention deficits, longer reaction times, increased errors and distractibility. Severe drowsiness can be a safety hazard, causing traffic crashes and workplace injuries, among other incidents.

In their conclusion of key findings, the Council found that some individuals residing in close proximity to wind turbines perceive audible noise and find it annoying, that these individuals report that this noise negatively affects their sleep, and that these events may result in other negative health effects. The Council minority concurs in this conclusion, illustrating the importance of effective siting laws to protect residents from the negative health effects of wind turbines.

3.1 Minority Reaction to Council Review and Significance of Annoyance

The term "annoyance" is used widely in the literature reviewed by the Council, and thus, is also used in the Council's report. The definition of annoyance selected by the Council majority is that referenced in a World Health Organization's (WHO) publication regarding occupation noise (*not* a peer-reviewed document reviewed by the Council), namely, "a feeling of resentment, displeasure, discomfort, dissatisfaction or offence which occurs when noise interferes with someone's thoughts, feelings or daily activities."

The Council minority does not believe this definition accurately represents the physiological response recognized by numerous studies showing an effect on human health. A paper published by the World Health Organization in 2011 states that WHO's definition of health *implies that noise-induced annoyance may be considered an adverse effect on health. (Miedema, H. et al, Burden of disease from environmental noise, WHO, 2011).*

As explained by Suter, A., (1991) "Annoyance" has been the term used to describe the community's collective feelings about noise ever since the early noise surveys in the 1950s and 1960s, although some have suggested that this term tends to minimize the impact. While "aversion" or "distress" might be more appropriate descriptors, their use would make comparisons to previous research difficult. Suter continues to expound on this thought, noting:

> *It should be clear, however, that "annoyance" can connote more than a slight irritation; it can mean a significant degradation in the quality of life. This represents a degradation of health in accordance with the WHO's definition of health, meaning total physical and mental well-being, as well as the absence of disease. (Suter, A., Noise and Its Effects, Administrative Conference of the United States, Editor. 1991).*

Other reputable studies reviewed by the Council, including Ellenbogen et al. (2012) and Shepherd et al. (2010), define "annoyance" as "a mental state characterized by distress and aversion, which if maintained, can lead to a deterioration of health and well-being", while Taylor, S. (2013) defines "annoyance" as connoted in contemporary medicine as being, "used as a precise technical term describing a mental state characterized by distress and aversion, which if maintained, can lead to deterioration in health and well-being".

Again, erring on the side of caution, the Council minority in its review of definitions of "annoyance", finds that the use of this term should be elevated to recognize its status as a technical term identifying events relating to the physiological definition of a medical condition with the potential to cause long-term chronic conditions.

3.2 Minority Reaction to Council Review on the Survey of Peer-reviewed Literature

The Council completed its initial survey of peer-reviewed wind-health literature and made recommendations to the Commission regarding wind siting rules in 2010. At that time the majority of the members recommended siting measures, including 50/45 dB(A) day/night noise limits, 1.1 times the maximum blade tip height setback and less than 40 hours of shadow flicker per year for non-participating residences. These recommendations were modified by the PSC and codified in *PSC 128, Wind Siting Rules*. A minority of the 2010 Council members strongly disagreed with these conclusions however, and their concerns were presented in Appendix E of the 2010 *Final Recommendations To the Public Service Commission: Wind Siting Rulemaking Pursuant to 2009 Wisconsin Act 40*. (see http://psc.wi.gov/apps35/ERF_view/viewdoc.aspx?docid=136311) The current Council minority affirms that position, and further asserts that these siting measures are recurrently inconsistent and outdated with developing research, noting that wind turbines generate sound that has components not even measured by the usual sound level meters when using a scale for normal audible sound, i.e. the dB(A) scale.

In their review of over 400 wind turbines installed throughout Wisconsin, the Council noted that some members of the public who reside near wind turbines have continued to complain about adverse human health impacts attributed to wind turbines. Unfortunately, the Council came to the incorrect and unsubstantiated conclusion that the level of public concern and amount of scientific or technical research associated with potential negative health impacts have diminished due to lack of interest or formal complaints. After complaining for a number of years and getting inadequate or no resolutions of the problems, residents have abandoned their homes or suffer in frustrated silence. The majority members of the Council did not allow reference to the complaint affidavits and local government resolutions in the Majority Report as requested by the minority members. Additionally, although PSC 128 requires wind project owners to maintain complaint logs and to submit them to the PSC upon request, the PSC has never requested such complaint logs and has not done so for this health review, although requested to do so by the Council Chairman, a minority member. Therefore, while PSC 128 directs all complainants to direct their complaints to the project owner, all such complaints have not been reviewed by the Council.

If proper weight were given to the empirical and anecdotal evidence of adverse effects of wind turbines on human health, we believe that the volume of reports of potential negative health impacts have not in fact diminished, but instead have increased, with any appearance to the contrary being the result of previous reports having either been disregarded or being submitted to the PSC and not acted upon.

When individuals report harmful effects or violations of the existing standards, no measure of accountability exists in Wisconsin law to ensure wind turbine operators are pursuing corrective action processes, thus resulting in an underreporting of noise violations. In order to better represent the true conditions under which adverse health reactions may in fact occur, a more efficient and comprehensive monitoring system of these noise levels, and a more responsive corrective action system, must be established to protect residents from noise violations.

In the study Pedersen (2011), the Council highlighted that although annoyance, sleep disturbance, and stress were linked to environmental noise, these effects are only attributable to wind turbines when they are generating sound levels over 40 dB(A). Yet, Wisconsin's wind siting rules allow daytime noise to be up to 50 dB(A) and nighttime noise to be up to 45 dB(A). Both are above the levels that were attributed to marked reactions in survey participants. As a point of reference, every step increase of 10 dB(A) results in a doubling of sound impact, i.e., 40 dB((A) is perceived as twice as loud as 30 dB(A) while 50 dB(A) is perceived as 4 times as loud as 30 dB(A).

Bakker et al. (2012), a separate analysis on a subset of the data from Pedersen (2011), found 23 percent of respondents reported annoyance from wind turbine noise to some degree while outdoors and 14 percent reported annoyance from turbines while indoors. This annoyance was directly related to noise level, with approximately 4 percent of annoyed respondents reporting annoyance where sound levels were less than 30 dB(A) and approximately 66 percent when they were above 45 dB(A), a trend that is also supported by experimental evidence in Ruotolo et al. (2012).

Sleep disturbance was reported by approximately 33 percent of respondents and it increased with greater environmental noise levels. The authors found that respondents were more annoyed by wind turbine noise than by road or rail noise when above 40 dB(A) and aircraft noise when above 45 dB(A). This occurs because of the unique characteristics of wind turbine-generated noise, which is long in duration (often 24/7) and has an amplitude modulated, or impulsive cadence. This constantly changing sound increases attention and cognitive appraisal and reappraisal, inhibiting acclimatization to the sound.

Janssen et. al. (2011), also concluded that annoyance from environmental noise increases rapidly as sound levels exceed 35 dB(A) outdoors and 40 dB(A) indoors. The study's authors found this to be especially true for wind turbine noise, with a large number of individuals reporting to be both annoyed or highly annoyed by wind turbines producing noise outdoors (approximately 40 percent of respondents) or indoors (approximately 18 percent of respondents) when sound levels are above 45 dB(A).

Furthermore, in Shepherd et al. (2011), the authors found that individuals residing in close proximity to turbines reported reductions in sleep quality, energy and overall quality of life. Nissenbaum et al. (2012) also showed similar results. Krogh et al. (2011) found that 94 percent of respondents self-reported altered health or quality of life specifically, and that 72 percent of participants reported experiencing stress, depression and sleep disturbance directly due to wind turbines.

Finally, the Council majority report omitted highly relevant facts from several studies that it relied heavily upon for its conclusions, including studies by Taylor, Crichton, Chapman, Katsaprakakis, and Mroczek, some of which also had serious design flaws. For specific examples of such reports, see Footnote 1 at the end of this report. Regrettably, and to the detriment of the reliability of the Majority Report, the Council majority voted to prematurely adopt the Wind-Health Report draft “as-is” prior to any adequate discussion of it in Council meetings. This barred correcting the deficiencies noted above.

It is important to note that it is incredibly difficult to design a control group in which there is no simulated placebo. The Council found that the limitations of available research confined the Council to only seven, unbiased, cross-sectional studies, of which three use the same data set. Again, the Council minority supports and recommends that more studies be commissioned in order to preserve and expand the diversity of data, but recommends, based on the evidence provided from available survey data, a highly cautionary approach to wind siting regulations.

3.3 Minority Reaction to Council Review on the Survey of Regulatory Developments

Besides the interpretation of the Council's majority that state and national regulatory developments shall not include those of foreign states or nations and shall not include results of studies commissioned by state or national government entities, even if in the U.S., the Council's majority also did not allow the Majority Report to include reports on the actions of various Wisconsin county boards, county boards of health, town boards and the Wisconsin Towns Association. These entities have passed resolutions or, otherwise, requested the PSC or the state to conduct additional studies to evaluate the health impact of wind turbines on the public. The PSC has not responded to these local government entities.

Similarly, the Majority Report does not include reference to the numerous complaints, affidavits, and testimonies of Wisconsin citizens regarding their health issues since wind turbines were put in operation near their homes. If the PSC would follow-up on these complaints in the field, as well as review complaint logs of wind project operators as mentioned above, a meaningful appreciation of the actual negative impacts upon people and an evaluation of the responses of wind project operators would significantly add to the PSC's body of knowledge and perhaps help mitigate the complaints.

The Council reviewed a summary of state regulations for wind turbine siting. Compiling such data is challenging since such regulations are often in a state of flux, state regulations often do not preempt local governments from having their own siting restrictions to suit local situations, and certain wind turbine siting regulations may be preempted by other state regulations regarding safety.

3.4 Majority Survey Conclusions and Minority Response

In their final review, the Council *unanimously* agreed that wind turbines have a physiological effect on some populations when in operation. The Majority Report stated:

> *What is not under dispute between these two groups is that wind turbines produce environmental noise, that some individuals find that noise annoying, and that environmental noise may cause sleep disruption if the sound levels are high enough. There is, as a result, a consensus that proper wind turbine siting is imperative when designing wind generating systems to reduce the impacts of noise on people.*

The Council suggests two pathways by which adverse health impacts may arise, including the stress/annoyance indirect pathway as well as the direct pathway of physiological perceptions and adverse reactions to inaudible infrasound and low-frequency noise (ILFN). Inaudible infrasound is generally considered to be sound below 20 hertz (Hz) while low frequency sound is generally considered to be sound in the range of 20 to 200 Hz. Note that infrasound and low-frequency noise (ILFN), when compared to audible noise, travels much farther, reflects more readily off the atmosphere and terrain, travels easier through walls, and resonates inside of buildings. It is important to observe that the current regulatory guidelines in Wisconsin do not regulate, monitor, or allow limits to infrasound and low frequency noise (ILFN).

Scientific measurements of infrasound and low frequency noise (ILFN) emissions by wind turbines have been thoroughly documented in studies such as the Shirley Wind Study (2012) commissioned by the PSC. Unfortunately, and to the detriment of studies regarding the adverse effects of wind turbines on human health, these acoustic measurements are not included in the WSC report simply because the measurements are only data sets and not considered peer-reviewed research. This acoustic testing in the Shirley Wind project was done by acoustic experts and could be considered more relevant than some peer-reviewed research. Significantly, the joint conclusion of the report states: *"The four investigating firms are of the opinion that enough evidence and hypotheses have been given herein to classify LFN and infrasound as a serious issue, possibly affecting the future of the industry."*

Although studies have shown infrasound and low frequency noise (ILFN) are harmful and have adverse health effects, a majority of those studies are not eligible for inclusion in this report due to the Council majority's interpretation of Wisconsin's statutory limits on scientific research to only include peer-reviewed data. Again, the Council minority disagrees with the Council majority's conclusion that there are no significant ill or adverse health effects, while such effects *are* indicated in both the literature reviewed by the Council *and* in a greater body of information excluded from review by the Council majority.

From the collections of data sets that are available, we can see infrasound and low frequency noise (ILFN) emissions from wind turbines have been identified, and that these emissions have the potential to cause physical harm in persons who are exposed to said sounds. Collaborative efforts from across many fields of science have discovered causal evidence of symptoms relating to wind turbine developments, thus requiring further analysis and study. Such studies must be carefully designed due to the challenges of structuring an experiment that involves an operating wind energy system in conjunction with human subjects. Wisconsin is an ideal place to conduct such studies due to the level of complaints and its relatively denser populations near wind turbines than in other states.

In their final conclusion, the Council minority and many subject experts disagree with the Council majority and believe there is sufficient data to infer that wind turbines have a direct and negative effect on human health based on their survey of applicable literature.

3.5 Minority Conclusion to the Health Section

The overwhelming empirical evidence from the peer-reviewed literature surveyed by the Council shows that when certain people are near operating wind turbines they become ill, but when the turbines are stopped, their conditions subside. Regardless of the reasons why, the law regulating the siting of turbines must protect the human rights and well-being of those living nearby and provide protection for innocent populations who are harmed by wind turbines sited too close to their homes - even if the mechanism of the harm is not yet fully understood.

The point is, there is enough causal evidence for alarm. We wholeheartedly agree with the Council majority opinion that more studies need to be commissioned to better understand the science surrounding these negative effects on human health. Also, the WSC's methodology for evaluating the litany of surveys and data sets every five years for the Legislature needs to be retooled to include previously excluded research and documented observations of human health impacts.

We must rethink setting maximum limits on regulation of wind turbines when the science has not been fully settled. The Hippocratic Oath, a physician’s rite of passage states, “I will prescribe regimens for the good of my patients according to my ability and my judgment and never do harm to anyone”. In the case of wind turbine siting, we must take a precautionary stance to preserve the health and well-being of all those who might otherwise suffer undue harm and not put limits or maximums on wind turbine regulations that have not been proven to be adequate.

In conclusion, existing evidence of physical harm caused by infrasound and low frequency noise (ILFN), coupled with the evidence that all wind energy systems emit infrasound and low frequency noise (ILFN) that is measurable at the homes of victims who report symptoms of low frequency noise, creates enough of a relationship that the Legislature and the PSC should act immediately to mitigate, through curtailment and other mandates, the harmful effects that have already been reported in Wisconsin. Most importantly, the Legislature and the PSC need to commission acoustic and epidemiological studies, conducted by independent experts, near Wisconsin wind turbine installations prior to construction of future systems to ensure that Wisconsin's regulations are not responsible for more harm to the health and safety of people living near wind energy systems. The four independent acoustic experts who conducted the acoustic study in the Shirley Wind project recommended "additional study on an urgent priority basis".

Also, the Legislature and the PSC should act to establish relief for those citizens who have been harmed by existing wind turbines in Wisconsin.

4.0 Minority Reaction to the Wind Siting Policy Update

Under s. 196.378(4g)(e) the Wind Siting Council is charged with reviewing developments in wind siting policy and providing a report with recommendations to the Legislature. Erroneously, the Council majority interpreted this charge to mean only regulatory developments from within the United States, and excluded review of regulatory developments in any other country.

Even within the narrow scope of this review, several key findings showed that Wisconsin's regulatory framework is unusual and does not do enough to protect the health of people living near wind turbines or the property rights of non-participating property owners in Wisconsin.

Wisconsin's regulatory environment is unusual in that regardless of the specific protections that might be appropriate for a proposed wind energy system, Wisconsin's wind siting rules create maximum limits that are more in line with most states' minimum standards and prevent Wisconsin local officials from offering ANY restrictions that would be more protective. In other words, Wisconsin's standards are the maximum protections that officials can impose, which is the opposite of how most regulations are written. Officials can never be more restrictive than these maximum protections for any reason under Wisconsin's wind siting rules.

4.1 Findings from the Regulatory Review

The Council did not acknowledge many regulatory developments in their Majority Report, but did rely heavily upon the 2012 National Association of Regulatory Utility Commissioners (NARUC) report. Several of the NARUC recommendations illustrate areas where Wisconsin's wind turbine siting regulations are inadequate even under the less than cautionary approach of NARUC's consultant who wrote the report.

Wind turbines in Wisconsin are allowed to subject people to audible sound levels that are twice as loud as the 2012 NARUC report recommends. NARUC recommends that 40 dB(A) should be an ideal design goal while Wisconsin law does not allow any restrictions to limit the noise below 50 dB(A) during the daytime. Because the dB(A) scale is a logarithmic scale, a 50 dB(A) sound is perceived as twice as loud as sound that is 40 dB(A) in amplitude.

The NARUC report recommends that noise standards should be based on land use. The report argues that doing so would incorporate background noise when considering siting, as the noise levels that may elicit annoyance may be washed out to some degree by background noise and thus not be as noticeable. However, PSC 128 does not consider background or ambient noise levels as some states do by setting their noise limit at 5 or 10 dB(A) over ambient, even though rural areas in Wisconsin where wind turbines are sited typically have nighttime ambient noise levels near 30dB(A).

The NARUC report also recommends that a clear monitoring, arbitration, and mitigation process be implemented to deal with resident complaints. Wisconsin's regulations are very lacking in this regard. While scores of Wisconsin residential complaints have been reported and logged by the PSC, the follow-up has generally been by phone calls. We are unaware of any official monitoring, in-field measurements, arbitration, or verified mitigation of any of the complaints. The NARUC report elaborates further that it is important for wind project developers and local officials who are approving the projects to have a transparent complaint review process that explicitly defines protocols for noise monitoring and mitigation. Wisconsin's wind siting laws forbid this, as any monitoring or mitigation requirements imposed by local jurisdictions would be stricter than the rigid framework that the current rules allow. PSC 128 does not require any noise monitoring, and consequently, PSC staff has explained that when noise violation complaints are received there is usually nothing they can do because there is no concurrent monitoring data to verify the noise violation. Additionally, PSC 128's complaint review process fails to make clear that unresolved complaints can be appealed to the PSC and how complainants are to make such an appeal. Finally, lacking any penalties for violations, PSC 128 provides no compliance incentive.

Accompanying greater experience with ever-larger wind turbines, the Council minority has observed a regulatory trend to create greater setbacks and lower noise limits as well as basing these limits on *property lines* rather than residence locations, even while Wisconsin continues to maintain 1250 feet or 3.1 times the total height, whichever is less, as the maximum allowable setback from a non-participant's *home*. States are beginning to learn the health impact lessons already learned in European countries and are slowly beginning to make necessary policy changes to protect public health.

Because the setbacks in Wisconsin are set from turbine to occupied structure, some property owners find that their buildable land is now within the 1250-foot setback, and they are no longer able to use their own property the way they wish due to health and safety concerns. This constitutes a "taking" of the non-participating landowners' property, and there is no protection from this scenario in Wisconsin's regulations. Regulations should protect non-participating property owners from being forced to place structures too close to wind turbines on adjacent properties, as the state of Ohio did in 2014 by now measuring their setback from the property line instead of from the residence.

Besides the setback from non-participating residences, PSC 128 limits the setback from participating residences and road right-of-ways of 1.1 times the turbine's total height to protect host or participating property owners from ice or turbine blade failure debris. This setback is inadequate. A review of actual incident reports of ice and debris throw indicates that a setback of at least 1.5 times should be a minimum. Engineering calculations have shown the possibility of broken turbine blades flying even much farther. The Council minority recommends that this minimum setback be established at 1.5 times the total height, not a maximum of 1.1 times to provide a logical distance and to allow for larger setbacks when circumstances require such.

Both Watson et al. (2012) and the NARUC report emphasize that a “one size fits all” setback standard is inappropriate. Watson et. al. describes competing interests between wind developers and local populations as a reason to vary the setback distances. The NARUC report recommends having setbacks that would meet necessary noise and shadow flicker restrictions, arguing that avoiding actual impacts on residents is of primary importance, rather than imposing what may be an arbitrary distance.

The NARUC report recommends establishing clear triggers for decommissioning, in addition to requiring wind energy system owners to have an escrow account to cover decommissioning costs. PSC 128 does not require an escrow account for decommissioning, but rather allows the wind developer to choose from a variety of less secure financial instruments or an escrow account.

It is very significant that the review revealed that the population density, in general, is higher in Wisconsin towns where wind projects are located than in towns where wind projects are located in all of Wisconsin’s neighboring states. This should support the assertion that greater protections be provided to the people who are living near these Wisconsin developments, as more people are being impacted due to the higher population density and the consequent practice of locating wind turbines closer to non-participating residences.

4.2 Conclusion for the Policy Review section

The Wind Siting Council’s majority members wrote in their conclusion to the Policy Review section nothing about the above discrepancies between Wisconsin’s wind siting laws and the NARUC recommendations, but instead wrote: “…Wisconsin should continue to provide a transparent regulatory and approval process for wind developers…”

The Council minority concludes instead that Wisconsin’s wind siting laws fall far short of the best practices that are recommended in the United States and falls even farther short of the best practices that are being implemented in other countries that have broader experience with wind energy than we do.

5.0 Minority Conclusion

The Council minority concludes that Wisconsin’s wind siting laws are not written to meet current standards or best practices to protect public health and safety, but instead are biased to favor wind project developers.

This bias is cemented by the statutory structure of the Wind Siting Council, seating several members who are linked either to the wind energy industry or to environmentalist groups that favor the green energy movement, leaving only a few members on the Council who aren't linked to those influences. This construct leaves the Legislature to be poorly advised by a biased Council majority.

This Council minority also asserts that PSC staff seems to also be biased toward the wind industry and PSC staff tended to downplay any dissenting reports that reflected poorly on Wisconsin's current wind siting laws. One reason for this seems to be that the PSC staff feels that the Legislature has given them a mandate to support wind and other renewables because of the statutory requirements for the Renewable Portfolio Standard (RPS) for utilities that are within the PSC's jurisdiction. The existence of the RPS creates a secondary status for health and safety.

It is important, both to the industry and residents, that residents have confidence in the wind siting laws of Wisconsin and that the laws are effective in protecting the health and safety of people who live near existing wind turbines. Effective laws help to reduce opposition to new projects.

6.0 Recommendations for Legislation:

Current Wisconsin law lacks an effective way for people who are suffering harm caused by existing wind turbines sited too close to their homes to seek effective mitigation or recourse. Wisconsin law needs to be changed to lay out a step-by-step complaint protocol with oversight by the PSC so wind turbine operators are held to the standards that are consistent with the standards and best practices highlighted in this Minority Report. PSC oversight is necessary to ensure accountability so complainants can expect resolution when a problem arises related to a nearby wind turbine.

It is important to change the current Wisconsin law that requires local officials to limit their protections for safety and health to the maximum allowed by PSC 128. Perhaps PSC 128 could become a model ordinance. Local officials should be able to meet their statutory obligation to protect the health and safety of the public and exceed limits of PSC 128 when such can be justified by qualified technical experts or licensed engineers. As studies reveal new standards and best practices or technology improves, officials should be able to require such to match the local conditions, such as geology, groundwater sensitivities, and population densities, or accommodate any unique specifications of the wind project to protect their residents.

Wisconsin law needs to change the local approval process for wind energy systems to allow local officials access to the PSC staff at no expense to the local unit of government. It is important to give local officials access to the same knowledge and experience that the PSC commissioners have when a wind siting application is considered. This assumes the legislature will clarify the PSC's role in protecting health and safety.

This Council minority strongly recommends acoustic and epidemiological studies be carried out, especially in Wisconsin where there are existing complaints of sleep disturbance, headaches, nausea, tinnitus, or much worse which appear to be related to existing wind energy systems. These studies should include measuring and analyzing the nature and effects of infrasound and low frequency noise (ILFN). If the studies find that negative health impacts are occurring when the wind turbines are operating within Wisconsin's current operation standards, a development moratorium should be enacted until the relationship between the wind turbine and the negative health impacts is fully understood. Until then, safe wind turbine siting standards are impossible to set. As the policy review highlighted, setbacks that avoid actual impacts on residents is of primary importance, rather than imposing what may be an arbitrary distance.

The legislature should develop a process to establish relief for those citizens who are verified to have been harmed by existing wind turbines in Wisconsin.

Wind turbine setbacks should also be set based on the distance of the turbine to a neighboring property line instead of the distance from the turbine to the structure of the neighbor's home. Wind projects with their multi-story heights and unique sound projections should follow the long-standing convention of measuring setbacks from property lines as with any other kind of structure or land use.

The statutory structure of the Wisconsin Wind Siting Council that creates the pro-wind bias within the Wind Siting Council must be changed through legislation. Also at issue are the statutory limits as to which studies and regulatory developments the Wind Siting Council may review when creating their report to the Legislature. Because of the bias and the limits in the document review to only include "peer-reviewed" studies, and regulatory review that is limited to only regulation changes from the United States, the Legislature gets a myopic view of the issues related to wind turbine siting.

This Council minority hopes this report and recommendations will help legislators create new wind siting laws that will restore confidence in Wisconsin's wind siting process.

Footnote 1 for Page 8

For example, the discussion of the favorable findings in the Katsaprakakis study left out the critical facts that the average distance from the 13 surveyed settlements to the small .5 MW turbines was over 4000' and the average noise level was only 32-36 dB(A). The majority report presents without qualification the obviously implausible findings of the Mroczek study - that respondents living nearest to wind turbines reported the highest quality of life while those living farthest away reported the opposite - but fails to mention the author's numerous qualifications regarding the probability that economic benefits were likely to be the largest factor affecting responses from participants, 48% of which were unemployed. The Taylor survey, which the majority report twice declares to be inapplicable to Wisconsin, considered 12 turbines averaging only **2** kw each (750 times smaller than a typical 1.5 MW Wisconsin turbine), yet included the article's findings in order to make the argument that reported adverse health effects are due primarily to negative attitudes toward wind turbines and not due to *real* health effects. The works by Crichton and Chapman, both advocates of the "it's all in your head hypothesis", are based on seriously flawed designs. For example, Chapman, whose "study" is very widely criticized as "junk science" by many highly qualified experts, relied almost exclusively on complaint logs from wind project owners to reach his conclusions.

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Appendix G

Summary of National Wind Siting Policies of all Fifty States and the District of Columbia

This table was compiled by surveying relevant wind-energy policy sources[1] and should not be considered an authoritative or exhaustive review of all national wind policies. Below is a summary of states' policies relevant to rules that are mandated under Wis. Admin. Code ch. PSC 128 for wind projects with a generating capacity of 100 MW or less.[2]

State	Relevant Policy, Primary Authority[3]	Mandatory or Voluntary[4]	Size	Noise	Property Setback	Residence Setback	Other Setbacks	Shadow Flicker	Decommissioning
Alabama	None, State	None	None	None	None	None	None	None	None
Alaska	None, State	None	None	None	None	None	None	None	None
Arizona	None, Local	None	None	None	None	None	None	None	None
Arkansas	None, Local	None	None	None	None	None	None	None	None
California	Yes, Local	Siting decisions made at county level; State mandatory maximum standards for local regulation of wind	≤ 50 kW	60 dB(A) for small wind or existing maximum (whichever is lesser) at property line	50 kW or less: Maximum setback from property line can be no more than tower height, unless greater setback is needed to comply with applicable fire setback under state Public Resources Code	None	None	None	None

State	Relevant Policy, Primary Authority[3]	Mandatory or Voluntary[4]	Size	Noise	Property Setback	Residence Setback	Other Setbacks	Shadow Flicker	Decommissioning
Colorado	Yes, Local	No state wind law or guidelines; State noise law	None	55 dB(A) day, 50 dB(A) night from property line	None	None	None	None	None
Connecticut	Yes, State	Mandatory; Connecticut Siting Council issues permits	Consumer < 65 MW, Utility > 65 MW	55 dB(A) day, 45 dB(A) night at the property line	2.5 times turbine height for >65 MW projects; 1.5 times turbine height for <65 MW projects or manufacturers recommendation, whichever is greater	None	None	Not more than 30 hours per year	Submit a decommissioning plan
Delaware	Yes, Local	Mandatory	Wind energy systems installed at single-family homes	≤ 5 dB(A) over ambient, up to 60 dB(A) at the property line	1.0 times turbine height	None	None	None	None
Florida	None, State	None	None	None	None	None	None	None	None
Georgia	Yes,* Local	Voluntary, Local jurisdictions are responsible for determining zoning/siting	None	55 dB(A) as measured at property line of non-	1.1 – 1.5 times turbine height, depending on capacity	1.5 – 2.5 times turbine height,	1.1 – 1.5 times turbine height, depending	Less than 30 hours per year	Submit a decommissioning plan

State	Relevant Policy, Primary Authority[3]	Mandatory or Voluntary[4]	Size	Noise	Property Setback	Residence Setback	Other Setbacks	Shadow Flicker	Decommissioning
		requirements, however the state provides a model ordinance		participating landowner		depending on capacity	on capacity		
Hawaii	None, Local	None	None	Wind projects must comply with Hawaii Dept. of Health Ch. 46 Community Noise Control Rules. Maximum permissible sound levels in dB(A) vary with zoning districts.	None	None	None	None	None
Idaho	None, Local	None	None	None	None	None	None	None	None
Illinois	Yes, Local	Mandatory state limit on small wind setback; other decisions	None	Wind projects are required to comply with	1.1 times turbine height	None	None	None	None

State	Relevant Policy, Primary Authority[3]	Mandatory or Voluntary[4]	Size	Noise	Property Setback	Residence Setback	Other Setbacks	Shadow Flicker	Decommissioning
		made at county level		Illinois' Pollution Control Board noise standards, approx. 45 dB(A) at property line.					
Indiana	None, Local	None	None	None	None	None	None	None	None
Iowa	Yes,* Both	Voluntary, Local jurisdictions are responsible for determining zoning/siting requirements, however the state provides a model ordinance	≤ 100 kW	A level that will not elicit nuisance	1.25 times turbine height	None	1.25 times turbine height for public/utility rights-of-way	None	None
Kansas	None, Local	None	None	None	None	None	None	None	None
Kentucky	Yes,* State	Voluntary, Local jurisdictions are responsible for determining zoning/siting requirements,	> 20 kW	55 dB(A) limit at occupied buildings of non-	1.5 times turbine height	2.0 times height for turbines > 20 kW and < 100 kW, 2.5 times for	1.5 times turbine height for public rights-of-way	Less than 30 hours per year	Submit a decommissioning plan

State	Relevant Policy, Primary Authority[3]	Mandatory or Voluntary[4]	Size	Noise	Property Setback	Residence Setback	Other Setbacks	Shadow Flicker	Decommissioning
		however the state provides a model ordinance		participating residences		turbines ≥ 100 kW			
Louisiana	None, Local	None	None	None	None	None	None	None	None
Maine	Yes,* State	Voluntary, Local jurisdictions are responsible for determining zoning/siting requirements, however the state provides a model ordinance	All capacities, however most recommendations regard ≥ 100 kW	55 dB(A) day/45 dB(A) night limit within 500 feet of a sleeping quarters, 55 dB(A) for protected areas, 75 dB(A) at property lines, 5 dB(A) penalty for repeating sounds	1.5 times turbine height	None	1.5 times turbine height for public/utility rights-of-way	Facility must be designed to "avoid unreasonable adverse" effects	Submit a decommissioning plan
Maryland	Yes, State	Voluntary (siting guidelines for wildlife), PSC regulates projects over 70 MW	None	None	None	None	None	None	None

State	Relevant Policy, Primary Authority[3]	Mandatory or Voluntary[4]	Size	Noise	Property Setback	Residence Setback	Other Setbacks	Shadow Flicker	Decommissioning
Massachusetts	Yes,* State	Voluntary, Local jurisdictions are responsible for determining zoning/siting requirements, however the state provides a model ordinance	≥ 600 kW	Not more than 10 dB(A) over ambient as measured at the property line of the facility or nearest inhabited buildings	1.5 times turbine height	3 times turbine height	1.5 times turbine height for public/utility rights-of-way	None	None
Michigan	Yes,* Local	Voluntary, Local jurisdictions are responsible for determining zoning/siting requirements, however the state provides a model ordinance	None	≤ 55 dB(A) or 5 dB(A) over ambient at property line	1 times turbine height	None	1 times height for public rights-of-way	Describe mitigation	Submit a decommissioning plan
Minnesota	Yes,* State	Mandatory, unless county affirmatively assumes jurisdiction on projects 5 - 25 MW	> 5 MW	55 dB(A) day, 50 dB(A) night, using state noise standard	Wind access buffer requires 3 rotor diameters on secondary wind axis, 5 diameters on primary wind access, from	500 feet from dwelling and sufficiently far to meet	250 feet from road rights-of-way	None	Submit a decommissioning plan

State	Relevant Policy, Primary Authority[3]	Mandatory or Voluntary[4]	Size	Noise	Property Setback	Residence Setback	Other Setbacks	Shadow Flicker	Decommissioning
					neighboring property, including public lands	noise standards			
Mississippi	None, State	None	None	None	None	None	None	None	None
Missouri	None, Local	None	None	None	None	None	None	None	None
Montana	None, Local	None	None	None	None	None	None	None	None
Nebraska	Yes, State	Mandatory decommissioning standard, all other siting guidelines are subject to local or county jurisdiction	None	None	None	None	None	None	Provide proof of available financial security for decommissioning costs

State	Relevant Policy, Primary Authority[3]	Mandatory or Voluntary[4]	Size	Noise	Property Setback	Residence Setback	Other Setbacks	Shadow Flicker	Decommissioning
Nevada	Yes, Local	Local jurisdiction over siting requirements; State restricts unacceptable limits on siting unless restrictions are due to noise, setback, health effects, etc.	None	None	None	None	None	None	None
New Hampshire	Yes, State	Mandatory limits not to be exceeded by municipalities	> 100 kW	Maximum 55 dB(A) at property lines	1.5 times turbine height	None	None	None	None
New Jersey	Yes, Both	Mandatory; Utility scale turbines must be installed on contiguous parcels ≥ 20 acres; limits on community scale projects	None	Maximum 55 dB(A) at property lines for community turbines	1.5 times turbine height for community project	None	None	None	None
New Mexico	None, State	None	None	None	None	None	None	None	None

State	Relevant Policy, Primary Authority[3]	Mandatory or Voluntary[4]	Size	Noise	Property Setback	Residence Setback	Other Setbacks	Shadow Flicker	Decommissioning
New York	Yes,* Local	Voluntary; except mandatory requirements for bat/bird surveys only, State regulation over 25 MW	None	55 dB(A) at property lines	1.5 times turbine height	None	None	None	None
North Carolina	Yes,* Local	Voluntary, Local jurisdictions are responsible for determining zoning/siting requirements	≥ 1 MW of turbine capacity within 0.5 miles between turbines	Maximum 55 dB(A) at occupied buildings	1.5 times turbine height	2.5 times turbine height	1.5 times turbine height to public rights-of-way	None	None
North Dakota	Yes, State	Mandatory for any wind project greater than 0.5 MW, smaller facilities regulated at local level	≥ 0.5 MW	50 dB(A) within 100 feet of inhabited residence or community building	1.1 times turbine height from property line of non-participating landowner, unless variance is granted.	None	1.1 times turbine height from inter/ state highway; same + 75 feet from county or town road centerline	None	None

State	Relevant Policy, Primary Authority[3]	Mandatory or Voluntary[4]	Size	Noise	Property Setback	Residence Setback	Other Setbacks	Shadow Flicker	Decommissioning
Ohio	Yes, State	Mandatory	≥ 5 MW	Model day/night levels and describe mitigation measures	1.1 times turbine height to wind farm property line and at least 1125 feet from tip of the turbine's nearest blade at ninety degrees to the nearest adjacent property line.	At least 1125 feet in horizontal distance from the tip of the turbine's nearest blade at ninety degrees to exterior of habitable, residential structure unless waived.	None	Model exposure and describe mitigation measures	None
Oklahoma	Yes, local	Mandatory decommissioning standard, all other siting guidelines are subject to local or county jurisdiction	None	None	None	None	None	None	After 15 years of operation, proof of financial security

State	Relevant Policy, Primary Authority[3]	Mandatory or Voluntary[4]	Size	Noise	Property Setback	Residence Setback	Other Setbacks	Shadow Flicker	Decommissioning
Oregon	Yes,* State	Voluntary, Local jurisdictions are responsible for determining zoning/siting requirements, however the state provides a model ordinance	≥ 50 kW	36 dB(A) or 10 dB(A) over ambient	1.5 times turbine height	None	None	None	None
Pennsylvania	Yes,* Local	Voluntary, Local jurisdictions are responsible for determining zoning/siting requirements, however the state provides a model ordinance	None	55 dB(A) at occupied buildings	1.1 times turbine height	5 times turbine height	1.1 times turbine height to public road	Owner should make a reasonable effort to minimize shadow flicker at residences	Submit a decommissioning plan and proof of financial security
Rhode Island	Yes,* State	Voluntary (recommendation – currently interim siting factors available)	Guidelines vary depending on size classification. Stated here are for >200	Individual noise study recommended. Recommended conformance with existing	1.5 times turbine height from all non-residential property lines	2 times height of turbine from residential property lines	1.25 to 1.5 times turbine height to rights-of-way	Communities to define amount, range of 3 to 30 hours per year provided.	None

State	Relevant Policy, Primary Authority[3]	Mandatory or Voluntary[4]	Size	Noise	Property Setback	Residence Setback	Other Setbacks	Shadow Flicker	Decommissioning
			feet height or 100 kW generation	municipality noise ordinances.					
South Carolina	None, State	None	None	None	None	None	None	None	None
South Dakota	Yes,* Local	Voluntary, Counties are responsible for determining zoning/siting requirements, however the state provides a model ordinance	≥ 75 feet tall	≤ 55 dB(A) at occupied building	500 feet or 1.1 times turbine height, whichever is greater, unless easement has been obtained from adjoining property owner.	1,000 feet for non-participant landowner; 500 feet or 1.1 times turbine height for participant landowner, whichever is greater.	500 feet or 1.1 times turbine height to public right-of-way, whichever is greater	None	Submit a decommissioning plan and proof of financial security after 10 years of operation
Tennessee	Yes,* Local	Voluntary, Local jurisdictions are responsible for determining zoning/siting requirements, however the state provides a model ordinance	> 20 kW	55 dB(A) limit at occupied buildings of non-participating residences	1.5 times turbine height	2.0 times height for turbines > 20 kW and < 100 kW, 2.5 times for turbines ≥ 100 kW	1.5 times turbine height for public rights-of-way	Less than 30 hours per year	Submit a decommissioning plan

State	Relevant Policy, Primary Authority[3]	Mandatory or Voluntary[4]	Size	Noise	Property Setback	Residence Setback	Other Setbacks	Shadow Flicker	Decommissioning
Texas	None, Local	None	None	None	None	None	None	None	None
Utah	Yes,* Local	Voluntary, Local jurisdictions are responsible for determining zoning/siting requirements, however the state provides a model ordinance	None	Existing limits or 60 dB(A)	None	1.1 times turbine height	1.1 times turbine height to public/utility rights-of-way	None	None
Vermont	None, State	None	None	None	None	None	None	None	None
Virginia	Yes,* Local	Voluntary, Local jurisdictions are responsible for determining zoning/siting requirements, however the state provides a model ordinance	> 5 MW or 2 or more turbines	60 dB(A) at property line	1.1 times turbine height	1.1 times turbine height; 1.5 times turbine height for non-participating landowner	None	Reasonable effort to minimize disruption	Submit a decommissioning plan and provide proof of financial security

State	Relevant Policy, Primary Authority[3]	Mandatory or Voluntary[4]	Size	Noise	Property Setback	Residence Setback	Other Setbacks	Shadow Flicker	Decommissioning
Washington	Yes, State	County jurisdiction, but projects can choose state Energy Facility Site Evaluation Council jurisdiction	None	State noise law, limits residential noise to 55 dB(A) day, 45 dB(A) night	None	None	None	None	None
Washington DC	None, PUC[5]	None	None	None	None	None	None	None	None
West Virginia	None, State	None	None	None	None	None	None	None	None
Wisconsin	Yes, Local[6]	Mandatory	Up to 100 MW	50 dB(A) Day, 45 dB(A) Night	1.1 times turbine height	Lessor of 1250 feet or 3.1 time height from nonparticipating residence	1.1 times turbine height from public/utility rights-of-way	No more than 30 hours per year, mitigation required if more than 20 hours per year	Maintain proof of financial security
Wyoming	Yes, State	Mandatory, Counties retain jurisdiction of siting requirements outside of	> 0.5 MW	None	1.1 times turbine height unless waived by landowners	1,000 feet or 5.5 times turbine heights, whichever is greater,	1.1 times turbine height to road, 5.5 times turbine	None	Submit a decommissioning plan

State	Relevant Policy, Primary Authority[3]	Mandatory or Voluntary[4]	Size	Noise	Property Setback	Residence Setback	Other Setbacks	Shadow Flicker	Decommissioning
		minimum setbacks defined by the state				unless waived by landowner	height (or minimum of 1000 feet) to "platted subdivisions", 1/2-mile to city limits		

***** State provides lesser jurisdictions with a model wind siting ordinance. The siting criteria in the model ordinances are recommendations and are not legally binding, unless otherwise noted.

[1] Sources include 1) Stanton (2012), 2) DSIRE: Database of State Incentives for Renewables & Efficiency, 3) internet searches regarding state policies and ordinances. Information is considered current up to 09/15/2014.

[2] PSC 128 also outlines rules on signal interference and stray voltage which are not addressed in this table. Wisconsin is the only state that has a policy for wind energy systems regarding stray voltage and one of only six states with policies regarding television or radio interference. Michigan's model, non-binding model ordinance recommends no siting that would cause signal interference, Oregon, New York, Virginia, and Pennsylvania recommend mitigation of interference and Wisconsin requires mitigation of interference.

[3] "Primary Authority" is taken directly from Stanton (2012).

[4] Note that some wind siting policies may be mandated by states (e.g., noise restrictions) while other policies may be regulated by local jurisdictions.

[5] Public Utility Commission

[6] May not be more restrictive than PSC 128.

Appendix H

Town of Newport, North Carolina, Adopted Ordinance on Property Protection

9-6.1(e) Real Property Value Protection Requirement

a. The WEF Owner (Applicant) or their successor shall assure The Town of Newport that there will be no loss in real property value due to the WEF.

b. To legally support this claim, the Applicant shall hereby consent to this Real Property Value Protection Agreement (“Agreement”). This Agreement provides assurance to nonparticipating real property owners near the WEF (not lessors to the Applicant), that they have some protections from real property values losses due to the WEF.

c. Applicant guarantees that the property values of all real property partially or fully within two (2) miles of the WEF, will not be adversely affected by the WEF. The two (2) miles shall be within the Newport Zoning and Planning Jurisdiction. Any real property owner(s) included in that area who believe that their property may have been devalued due to the WEF, may elect to exercise the following option:

d. All appraiser costs are paid by the Applicant, from the Escrow Account. Applicant and the property owner shall each select a licensed appraiser. Each appraiser shall provide a detailed written explanation of the reduction in value to the real property ("Diminution Value"), if any, caused by the proximity to the WEF. This shall be determined by calculating the difference between the current fair market value of the real property (assuming no WEF was proposed or constructed), and the fair market value at the time of exercising this option:

1. If the higher of the Diminution Valuations submitted is equal to or less than twenty five percent (25%) more than the other, the two values shall be averaged ("Average Diminution Value": ADV).
2. If one of the Diminution Valuations submitted is more than twenty five percent (25%)higher than the other, then the two appraisers will select a third licensed appraiser who shall present to Applicant and property owner a written appraisal report as to the Diminution Value for the real property. The parties agree that the resulting average of the two highest Diminution Valuations shall constitute the ADV.
3. In either case, the property owner may elect to receive payment from the WEF Owner of the ADV. Applicant is required to make this payment within sixty (60) days of receiving said written election from property owner, to have such payment made.

e. Other Agreement Conditions:

1. If a property owner wants to exercise this option, they must do so within ten (10) years of the WEF receiving final approval from the town.
2. A property owner may elect to exercise this option only once.
3. The applicant and the property owner may accept mutually agreeable modifications of this Agreement, however, the Applicant is not allowed to put other conditions on a financial settlement (e.g. confidentiality). If the property owner accepts some payment for property value loss, based on an alternative method, then that is considered an exercise of this option.
4. This Agreement applies to the property owner of record as of the first notification of intent to apply for a WEF permit by the Applicant to DENR, as required by HB-484, is not transferable to subsequent property owners.

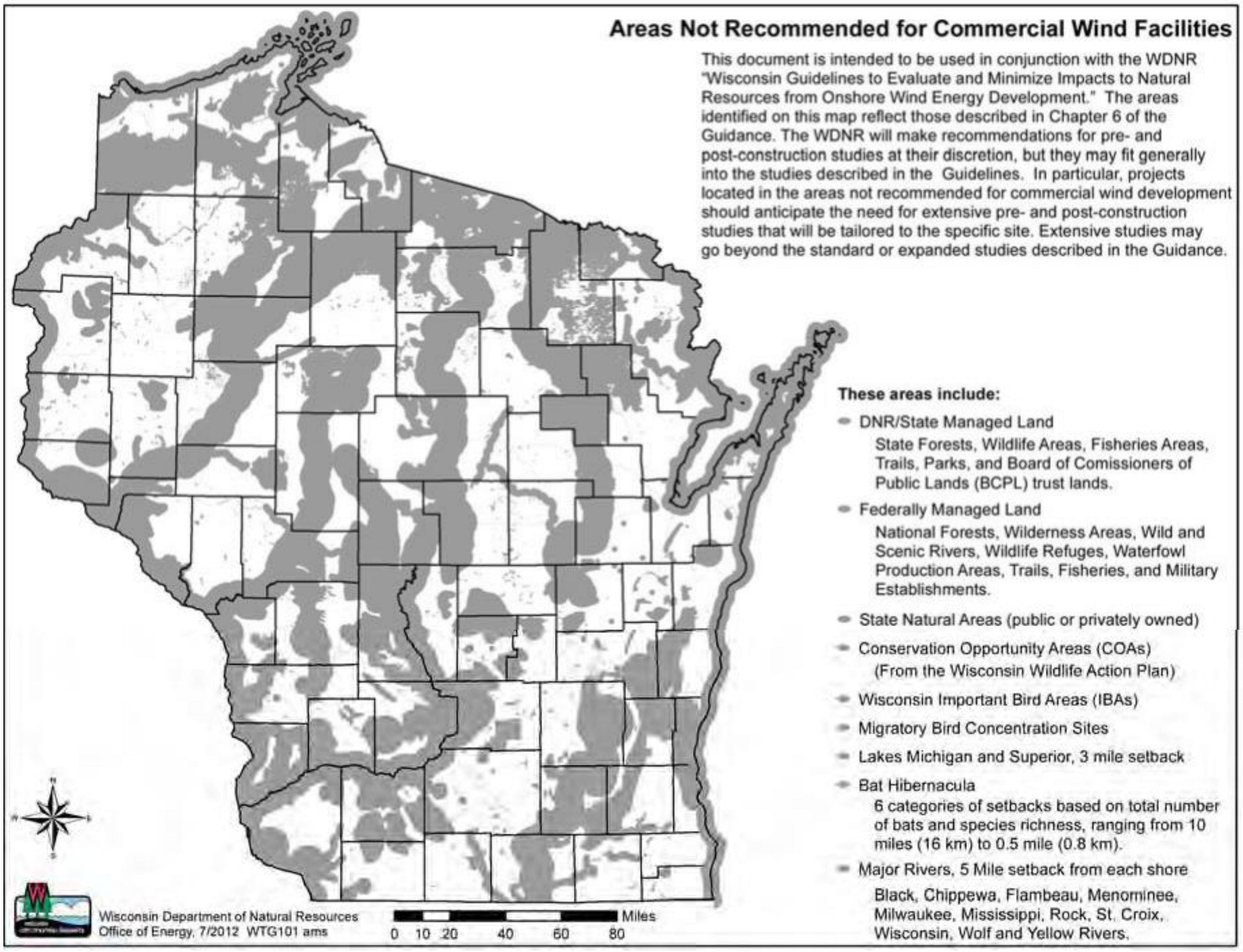
5. The property owner of record as of the first notification of intent to apply for a WEF permit by the Applicant to DENR, as required by HB-484, must reasonably maintain the property from that time, until they choose to elect this option.
6. The property owner must permit access to the property by the appraisers, as needed to perform the appraisals.
7. The property owner must inform the appraisers of all known defects of the property as may be required by law, as well as all consequential modifications or changes to the property subsequent to the first notification of intent to apply for a WEF permit by the Applicant to DENR, as required by HB-484.
8. This Agreement will be guaranteed by the Applicant (and all its successors and assigns), for ten (10) years following the WEF receiving final approval from the Town, by providing a bond (or other surety), in an amount determined to be acceptable by the Town.
9. Payment by the Applicant (per 9-6.1(e)d.3.) not made within sixty (60) days will accrue an interest penalty. This will be twelve (12) percent annually, from the date of the written election from property owner.
10. For any litigation regarding this matter, all reasonable legal fees and court costs will be paid by the Applicant.

Appendix I

Guidance for Minimizing Impacts to Natural Resources from Terrestrial Commercial Wind Energy Development

The Wisconsin DNR has developed guidance to aid in the planning of commercial wind energy facilities. The guidance was developed to help wind project reviewers, planners and owners identify areas that are not suitable for wind development, address potential impacts, and prevent unwanted and avoidable conflicts with area or site-specific natural resource management objectives. This guidance is consistent with general guidance from the US Fish and Wildlife Service, but is guidance, and not a formal regulatory framework. The DNR does have regulatory authority over certain aspects of wind energy system development, including any wetland or waterway impacts, erosion control and protection of state-listed threatened or endangered species.

For the full guidance document, please visit the WI DNR website at:
http://dnr.wi.gov/topic/sectors/documents/energy/windguidelines.pdf



Areas Not Recommended for Commercial Wind Facilities

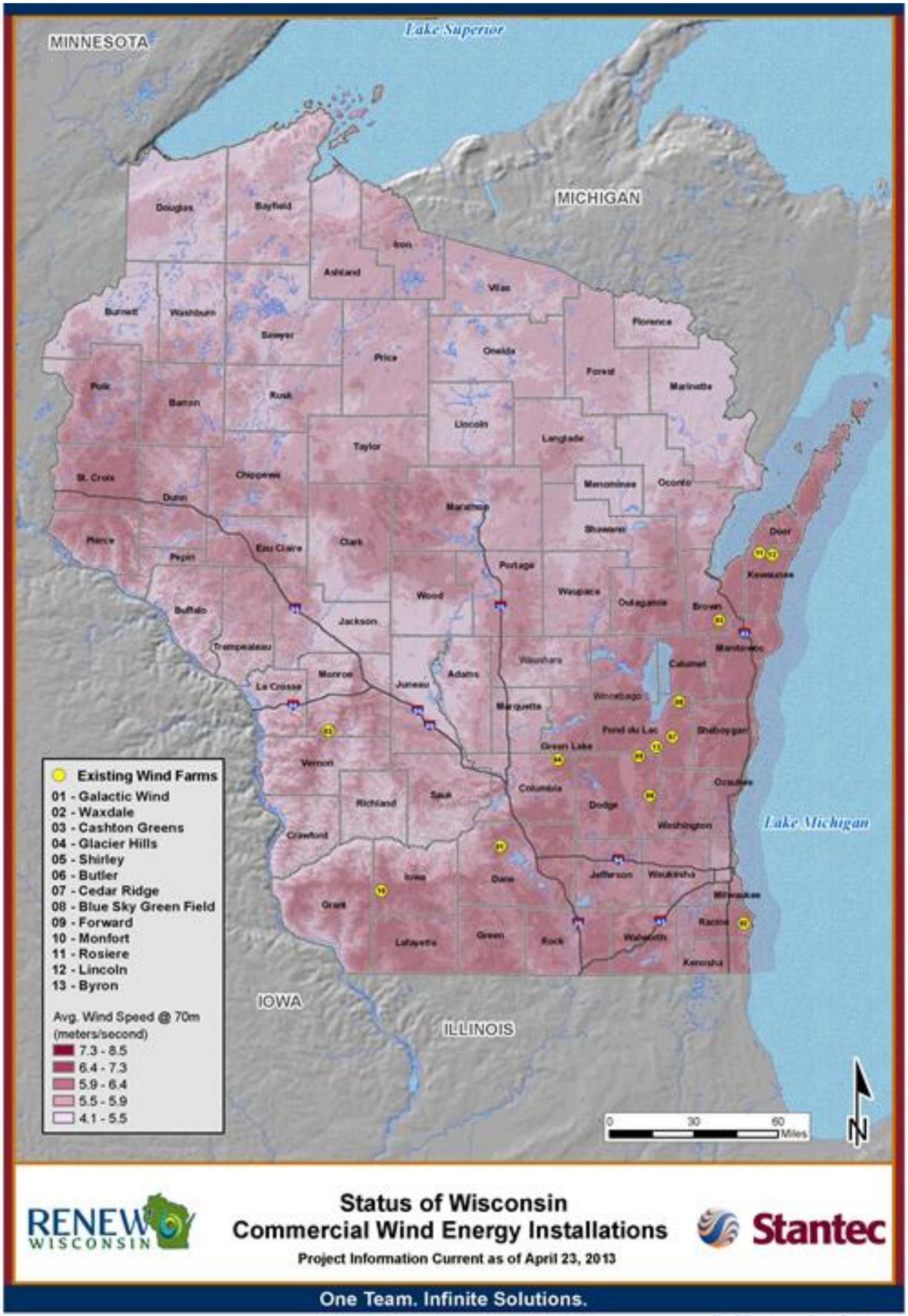
This document is intended to be used in conjunction with the WDNR "Wisconsin Guidelines to Evaluate and Minimize Impacts to Natural Resources from Onshore Wind Energy Development." The areas identified on this map reflect those described in Chapter 6 of the Guidance. The WDNR will make recommendations for pre- and post-construction studies at their discretion, but they may fit generally into the studies described in the Guidelines. In particular, projects located in the areas not recommended for commercial wind development should anticipate the need for extensive pre- and post-construction studies that will be tailored to the specific site. Extensive studies may go beyond the standard or expanded studies described in the Guidance.

These areas include:

- DNR/State Managed Land
  State Forests, Wildlife Areas, Fisheries Areas, Trails, Parks, and Board of Comissioners of Public Lands (BCPL) trust lands.
- Federally Managed Land
  National Forests, Wilderness Areas, Wild and Scenic Rivers, Wildlife Refuges, Waterfowl Production Areas, Trails, Fisheries, and Military Establishments.
- State Natural Areas (public or privately owned)
- Conservation Opportunity Areas (COAs)
  (From the Wisconsin Wildlife Action Plan)
- Wisconsin Important Bird Areas (IBAs)
- Migratory Bird Concentration Sites
- Lakes Michigan and Superior, 3 mile setback
- Bat Hibernacula
  6 categories of setbacks based on total number of bats and species richness, ranging from 10 miles (16 km) to 0.5 mile (0.8 km).
- Major Rivers, 5 Mile setback from each shore
  Black, Chippewa, Flambeau, Menominee, Milwaukee, Mississippi, Rock, St. Croix, Wisconsin, Wolf and Yellow Rivers.

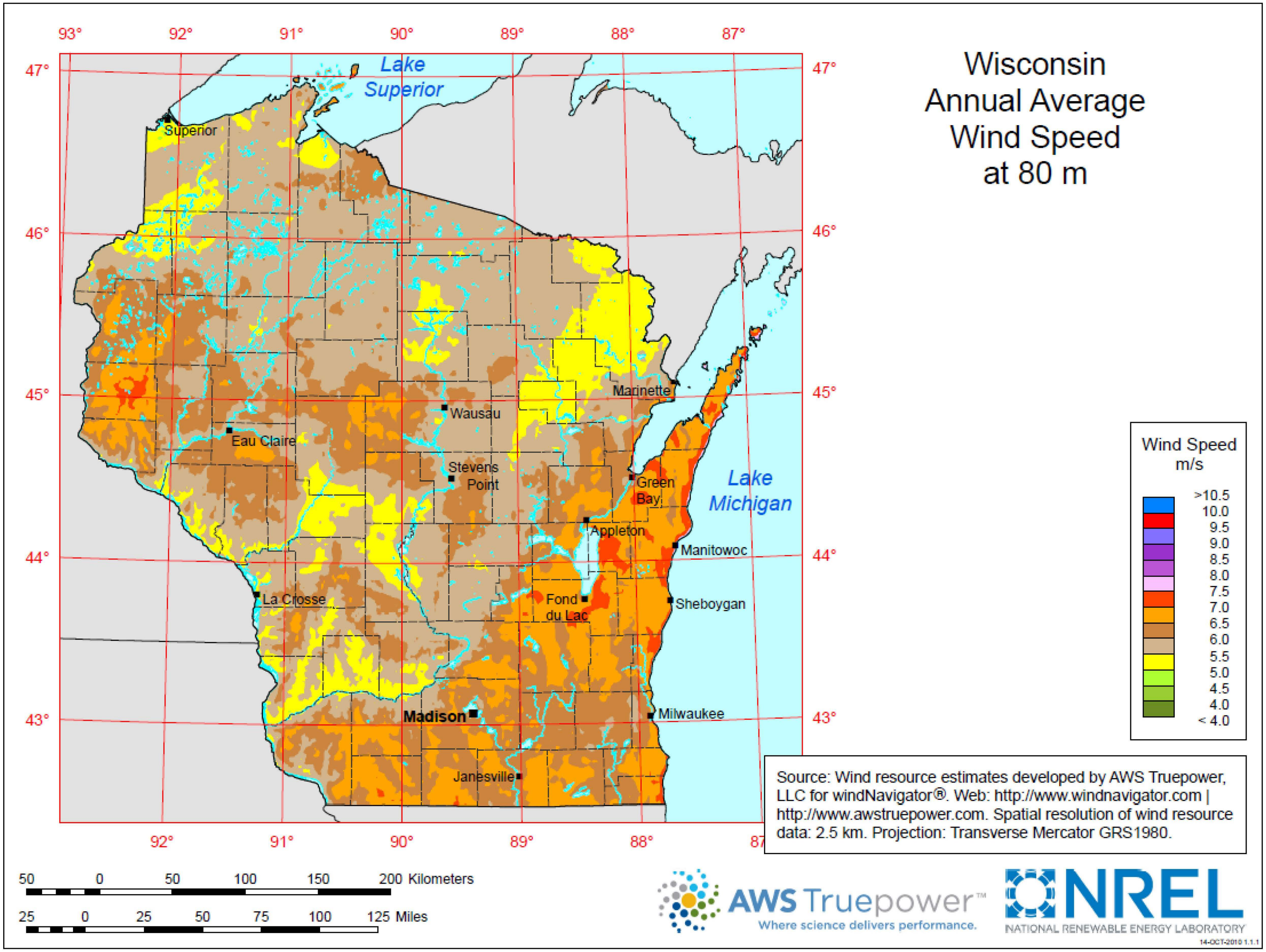
Wisconsin Department of Natural Resources
Office of Energy, 7/2012 WTG101 ams

Appendix J: Map of Commercial Wind Energy Installations in Wisconsin 1998-2013



Map Author: alexander.brasch@stantec.com

Appendix K: Map Showing Wisconsin Annual Average Wind Speed at 80 Meters



Wisconsin Annual Average Wind Speed at 80 m

Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: Transverse Mercator GRS1980.

Appendix L: Population Densities in areas of Midwestern Wind Energy System Development

The purpose of this spreadsheet is to provide population density data, at the township level, for the major wind projects in operation in six Midwestern states: Wisconsin, Minnesota, Michigan, Illinois, Iowa, and Indiana. An effort was made to identify wind energy systems and their associated townships. Although wind project county locations are readily available, oftentimes township location data is not provided. In such cases, email inquiries were sent to county officials in the respective project location counties, requesting the names of the townships in which specific wind projects were located. Requests were sent to multiple officials in each county and included emails to county assessors, recorders, surveyors, engineers or GIS/mapping personnel, planning department supervisors, and county clerks.

Responses were gathered and compiled in this spreadsheet. In some cases, county officials provided additional wind project township information for projects not specifically requested. In those cases, those wind project names and townships were added to the spreadsheet. 2010 population density data was then gathered from the U.S. Census Bureau website and added to the spreadsheet. The population density data for both the counties and the townships where the listed wind projects were located within each state were each added together and divided by the number of counties or townships listed, respectively, to arrive at the average population per square mile for the counties and townships in each state. Where there were multiple wind energy systems in either a town or county, the values for those were not additionally summed for the average, but rather each added once to the calculation of the average. For states in the Upper Midwest, Wisconsin shows a comparatively higher population density at the county and township level in areas where there has been wind energy system development.

This approach is useful in allowing for a quick comparison of population densities at the county and town level, however, dense population centers within some counties or townships will influence the results and may create data outliers that are not accurate representations of the population density in the areas immediately surrounding wind energy systems. Other potential ways of comparing population densities around wind energy systems such as evaluating population density within a specified distance around each system, or assessing population density down to the square mile, present difficulties in obtaining the data needed for comparison.

Below is a summary table of the state comparison data, with a more detailed table that follows; showing the particular wind energy systems, counties, and towns that form the basis for the assessment.

State	Illinois	Indiana	Iowa	Michigan	Minnesota	Wisconsin
County Population Density per Sq.Mi. where Wind Energy Systems exist	84	105.8	21.8	101.5	27.1	163.2
Town Population Density per Sq. Mi. where Wind Energy Systems exist	28.5	24.3	11.3	30	7.6	35.1

Wind Project	**MW Capacity**	**State**	**County**	**Pop/Sq.Mi.**	**Township**	**Pop/Sq.Mi.**	**Census Reference**
Big Sky Wind Farm	240	Illinois	Bureau	40.2	Ohio	21.6	CPH-2-15 p.15
Big Sky Wind Farm	240	Illinois	Bureau	40.2	Walnut	47.5	CPH-2-15 p.15
Big Sky Wind Farm	240	Illinois	Lee	49.7	East Grove	7.2	CPH-2-15 p.43
Big Sky Wind Farm	240	Illinois	Lee	49.7	May	8.6	CPH-2-15 p.43
Bishop Hill 1	200	Illinois	Henry	61.3	Weller	12.3	CPH-2-15 p. 32
Bishop Hill 1	200	Illinois	Henry	61.3	Cambridge	68.4	CPH-2-15 p. 32
Bishop Hill 1	200	Illinois	Henry	61.3	Galva	82.8	CPH-2-15 p. 32
Bishop Hill 1	200	Illinois	Henry	61.3	Burns	7.3	CPH-2-15 p. 32
Bishop Hill 1	200	Illinois	Henry	61.3	Clover	26.9	CPH-2-15 p. 32
Grand Ridge	210	Illinois	LaSalle	100.4	Grand Rapids	9.4	CPH-2-15 p. 42
Grand Ridge	210	Illinois	LaSalle	100.4	Brookfield	23.9	CPH-2-15 p. 41
Grand Ridge	210	Illinois	LaSalle	100.4	Otter Creek	82.9	CPH-2-15 p. 42
Lee-Dekalb Wind Energy Center	217.5	Illinois	DeKalb	166.6	Milan	9.4	CPH-2-15 p. 24
Lee-Dekalb Wind Energy Center	217.5	Illinois	DeKalb	166.6	Afton	24.5	CPH-2-15 p. 23
Lee-Dekalb Wind Energy Center	217.5	Illinois	DeKalb	166.6	Shabbona	42	CPH-2-15 p. 24
Lee-Dekalb Wind Energy Center	217.5	Illinois	DeKalb	166.6	Clinton	53	CPH-2-15 p. 23
Lee-Dekalb Wind Energy Center	217.5	Illinois	Lee	49.7	Alto	16.2	CPH-2-15 p. 43
Lee-Dekalb Wind Energy Center	217.5	Illinois	Lee	49.7	Willow Creek	19.6	CPH-2-15 p. 43
Minonk	200	Illinois	Woodford	73.3	Panola	9.7	CPH-2-15 p. 72

Wind Project	MW Capacity	State	County	Pop/Sq.Mi.	Township	Pop/Sq.Mi.	Census Reference
Minonk	200	Illinois	Woodford	73.3	Minonk	62.6	CPH-2-15 p. 72
Minonk	200	Illinois	Livingston	37.3	Nebraska	39.3	CPH-2-15 p. 44
Minonk	200	Illinois	Livingston	37.3	Waldo	7	CPH-2-15 p. 44
Streator Cayuga Ridge South Wind Farm	300	Illinois	Livingston	37.3	Odell	35.4	CPH-2-15 p. 44
Streator Cayuga Ridge South Wind Farm	300	Illinois	Livingston	37.3	Union	6.8	CPH-2-15 p. 44
Streator Cayuga Ridge South Wind Farm	300	Illinois	Livingston	37.3	Saunemin	15.4	CPH-2-15 p. 44
Top Crop Wind Farm	300	Illinois	LaSalle	100.4	Grand Rapids	9.4	CPH-2-15 p. 42
Top Crop Wind Farm	300	Illinois	LaSalle	100.4	Brookfield	23.9	CPH-2-15 p. 41
Top Crop Wind Farm	300	Illinois	LaSalle	100.4	Otter Creek	82.9	CPH-2-15 p. 42
Twin Groves Wind Farms I & II	396	Illinois	McLean	143.3	Arrowsmith	13.9	CPH-2-15 p. 46
Twin Groves Wind Farms I & II	396	Illinois	McLean	143.3	Dawson	15.8	CPH-2-15 p. 46
Twin Groves Wind Farms I & II	396	Illinois	McLean	143.3	Cheney's Grove	27.3	CPH-2-15 p. 46
Average County Pop/Sq.Mi. (Illinois Projects)			**84**				
Average Township Pop/Sq.Mi. (Illinois Projects)			**28.5**				

Wind Project	MW Capacity	State	County	Pop/Sq.Mi.	Township	Pop/Sq.Mi.	Census Reference
Benton County Wind Farm	130	Indiana	Benton	21.8	Richland	15.1	CPH-2-16 p. 14
Benton County Wind Farm	130	Indiana	Benton	21.8	York	6.6	CPH-2-16 p. 14

Fowler Ridge (multiple phase)	600	Indiana	Benton	21.8	Bolivar	34.7	CPH-2-16 p. 14
Fowler Ridge (multiple phase)	600	Indiana	Benton	21.8	Center	51.2	CPH-2-16 p. 14
Fowler Ridge (multiple phase)	600	Indiana	Benton	21.8	Grant	29.4	CPH-2-16 p. 14
Fowler Ridge (multiple phase)	600	Indiana	Benton	21.8	Hickory Grove	14.2	CPH-2-16 p. 14
Fowler Ridge (multiple phase)	600	Indiana	Benton	21.8	Oak Grove	44.5	CPH-2-16 p. 14
Fowler Ridge (multiple phase)	600	Indiana	Benton	21.8	Parish Grove	5.3	CPH-2-16 p. 14
Fowler Ridge (multiple phase)	600	Indiana	Benton	21.8	Union	7.1	CPH-2-16 p. 14
Hoosier	106	Indiana	Benton	21.8	Pine	9.3	CPH-2-16 p. 14
Hoosier	106	Indiana	Benton	21.8	Union	7.1	CPH-2-16 p. 14
Hoosier	106	Indiana	Benton	21.8	Gilboa	7	CPH-2-16 p. 14
Wildcat	200	Indiana	Madison	291.3	Duck Creek	22.9	CPH-2-16 p. 29
Wildcat	200	Indiana	Madison	291.3	Boone	21.9	CPH-2-16 p. 29
Wildcat	200	Indiana	Tipton	61.2	Madison	31.3	CPH-2-16 p. 39
Wildcat	200	Indiana	Tipton	61.2	Wildcat	40.8	CPH-2-16 p. 39
Meadow Lake (Phase I, II, III)	402	Indiana	White	48.8	Prairie	47.8	CPH-2-16 p. 43
Meadow Lake (Phase I, II, III)	402	Indiana	White	48.8	Big Creek	24.8	CPH-2-16 p. 43
Average County Pop/Sq.Mi. (Indiana Projects)			**105.8**				
Average Township Pop/Sq.Mi. (Indiana Projects)			**24.3**				

Wind Project	MW Capacity	State	County	Pop/Sq.Mi.	Township	Pop/Sq.Mi.	Census Reference
Adair Wind Farm	174	Iowa	Cass	24.7	Massena	14.7	CPH-2-17 p. 19
Barton Wind Farm	160	Iowa	Worth	19	Barton	5.3	CPH-2-17 p. 58
Buena Vista (Storm Lake)	193	Iowa	Buena Vista	35.2	Maple Valley	6.3	CPH-2-17 p. 17
Century Wind Farm	200	Iowa	Hamilton	27.2	Blairsburg	10.3	CPH-2-17 p. 30
Century Wind Farm	200	Iowa	Wright	22.8	Wall Lake	3	CPH-2-17 p. 59
Century Wind Farm	200	Iowa	Wright	22.8	Vernon	2.9	CPH-2-17 p. 59
Crystal Lake Wind Farm	416	Iowa	Hancock	19.9	Crystal	12.4	CPH-2-17 p. 31
Crystal Lake Wind Farm	416	Iowa	Hancock	19.9	Bingham	12.1	CPH-2-17 p. 31
Crystal Lake Wind Farm	416	Iowa	Hancock	19.9	Orthel	6.2	CPH-2-17 p. 31
Crystal Lake Wind Farm	416	Iowa	Hancock	19.9	Britt	64.7	CPH-2-17 p. 31
Eclipse Wind Project	200	Iowa	Audubon	13.8	Audubon	5.3	CPH-2-17 p. 14
Eclipse Wind Project	200	Iowa	Guthrie	18.5	Grant	5.4	CPH-2-17 p. 30
Franklin County Wind Farm		Iowa	Franklin	18.4	Hamilton	4.3	CPH-2-17 p. 28
Franklin County Wind Farm		Iowa	Franklin	18.4	Oakland	5.9	CPH-2-17 p. 28
Franklin County Wind Farm		Iowa	Franklin	18.4	Lee	4.9	CPH-2-17 p. 28
Franklin County Wind Farm		Iowa	Franklin	18.4	Grant	9.2	CPH-2-17 p. 28
Gamesa Wind Farm		Iowa	Pocahontas	13	Colfax	4.4	CPH-2-17 p. 47
Gamesa Wind Farm		Iowa	Pocahontas	13	Bellville	9.7	CPH-2-17 p. 47
Gamesa Wind Farm		Iowa	Pocahontas	13	Lizard	5.5	CPH-2-17 p. 47
Garden Wind Farm		Iowa	Hardin	30.8	Sherman	20.5	CPH-2-17 p. 32
Garden Wind Farm		Iowa	Hardin	30.8	Concord	9.7	CPH-2-17 p. 31

Wind Project	MW Capacity	State	County	Pop/Sq.Mi.	Township	Pop/Sq.Mi.	Census Reference
Garden Wind Farm		Iowa	Hardin	30.8	Grant	6.6	CPH-2-17 p. 32
Intrepid Wind Farm	160	Iowa	Buena Vista	35.2	Maple Valley	6.3	CPH-2-17 p. 17
Intrepid Wind Farm	160	Iowa	Sac	18	Cook	4.5	CPH-2-17 p. 50
Intrepid Wind Farm	160	Iowa	Sac	18	Eureka	26.1	CPH-2-17 p. 50
Morning Light Wind Project		Iowa	Adair	13.5	Summit	27.2	CPH-2-17 p. 13
Morning Light Wind Project		Iowa	Adair	13.5	Walnut	5	CPH-2-17 p. 13
Morning Light Wind Project		Iowa	Adair	13.5	Prussia	4.9	CPH-2-17 p. 13
Pioneer Prairie Wind Farm	293	Iowa	Howard	20.2	Oak Dale	6.5	CPH-2-17 p. 33
Pioneer Prairie Wind Farm	293	Iowa	Mitchell	23	Stacyville	24.3	CPH-2-17 p. 43
Pioneer Prairie Wind Farm	293	Iowa	Mitchell	23	Wayne	12.6	CPH-2-17 p. 43
Pomeroy Wind Farm	286	Iowa	Pocahontas	12.7	Cedar	21.2	CPH-2-17 p. 47
Pomeroy Wind Farm	286	Iowa	Pocahontas	12.7	Colfax	4.4	CPH-2-17 p. 47
Pomeroy Wind Farm	286	Iowa	Pocahontas	12.7	Grant	4.1	CPH-2-17 p. 47
Pomeroy Wind Farm	286	Iowa	Calhoun	17	Butler	24.5	CPH-2-17 p. 18
Rolling Hills Wind Project	444	Iowa	Adair	13.5	Jackson	9.7	CPH-2-17 p. 13
Rolling Hills Wind Project	444	Iowa	Adair	13.5	Washington	4.1	CPH-2-17 p. 13
Story County Wind Farm I & II	300	Iowa	Hardin	30.8	Sherman	20.5	CPH-2-17 p. 32
Story County Wind Farm I & II	300	Iowa	Hardin	30.8	Concord	9.7	CPH-2-17 p. 31
Story County Wind Farm I & II	300	Iowa	Hardin	30.8	Grant	6.6	CPH-2-17 p. 32
Top of Iowa (I,II,II)	190	Iowa	Worth	19	Brookfield	6.6	CPH-2-17 p. 58

Wind Project	MW Capacity	State	County	Pop/Sq.Mi.	Township	Pop/Sq.Mi.	Census Reference
Top of Iowa (I,II,II)	190	Iowa	Worth	19	Danville	9.7	CPH-2-17 p. 58
Whispering Willow Wind Farm	200	Iowa	Franklin	18.4	Hamilton	4.3	CPH-2-17 p. 28
Whispering Willow Wind Farm	200	Iowa	Franklin	18.4	Reeve	7.4	CPH-2-17 p. 28
Whispering Willow Wind Farm	200	Iowa	Franklin	18.4	Lee	4.9	CPH-2-17 p. 28
Whispering Willow Wind Farm	200	Iowa	Franklin	18.4	Grant	9.2	CPH-2-17 p. 28
Average County Pop/Sq.Mi. (Iowa Projects)			**21.8**				
Average Township Pop/Sq.Mi. (Iowa Projects)			**11.3**				

Wind Project	MW Capacity	State	County	Pop/Sq.Mi.	Township	Pop/Sq.Mi.	Census Reference
Beebe Wind Farm	82	Michigan	Gratiot	74.7	Emerson	27.8	CHP-2-24 p. 22
Beebe Wind Farm	82	Michigan	Gratiot	74.7	North Star	26	CHP-2-24 p. 23
Beebe Wind Farm	82	Michigan	Gratiot	74.7	Hamilton	13.4	CHP-2-24 p. 23
Garden Wind Farm	8	Michigan	Delta	31.7	Garden	4.7	CHP-2-24 p. 20
Gratiot Farms	213	Michigan	Gratiot	74.7	Lafayette	16.4	CHP-2-24 p. 23
Gratiot Farms	213	Michigan	Gratiot	74.7	Emerson	27.8	CHP-2-24 p. 22
Gratiot Farms	213	Michigan	Gratiot	74.7	North Star	26	CHP-2-24 p. 23
Lake Winds Energy Park	101	Michigan	Mason	58	Riverton	32.7	CHP-2-24 p. 32
Lake Winds Energy Park	101	Michigan	Mason	58	Summit	72.2	CHP-2-24 p. 32
Michigan Wind 2	90	Michigan	Sanilac	44.8	Minden	15.1	CHP-2-24 p. 42

Michigan Wind 2	90	Michigan	Sanilac	44.8	Bridgehampton	23.6	CHP-2-24 p. 41
Michigan Wind 2	90	Michigan	Sanilac	44.8	Delaware	18.4	CHP-2-24 p. 41
Michigan Wind 2	90	Michigan	Sanilac	44.8	Marion	46	CHP-2-24 p. 42
Pheasant Run Wind 1	75	Michigan	Huron	39.6	Brookfield	21.4	CHP-2-24 p. 24
Thumb Wind Park	34	Michigan	Sanilac	44.8	Delaware	18.4	CHP-2-24 p. 41
Thumb Wind Park	34	Michigan	Sanilac	44.8	Marion	46	CHP-2-24 p. 42
Thumb Wind Park	34	Michigan	Sanilac	44.8	Minden	15.1	CHP-2-24 p. 42
Tuscola Bay Wind	120	Michigan	Tuscola	69.4	Gilford	21.3	CHP-2-24 p. 43
Tuscola Bay Wind	120	Michigan	Tuscola	69.4	Akron	28.5	CHP-2-24 p. 42
Tuscola Bay Wind	120	Michigan	Bay	243.7	Merritt	45.5	CHP-2-24 p. 15
Tuscola Bay Wind	120	Michigan	Saginaw	250.2	Blumfield	55	CHP-2-24 p. 40
Wind project name and township data shown in the following eight line grouping for Huron County was received from a Huron County official, but the response did not itemize which of the provided projects were located in which of the provided townships, but only that these projects exist in Huron County and that they are located in the various townships listed. Therefore, the particular Huron County township listed in this grouping may not necessarily correspond to the particular Huron County wind project located on the same line in the table where the township is listed.							
		Michigan	Huron	39.6	Brookfield	21.4	CHP-2-24 p. 24
Big Turtle Wind	20	Michigan	Huron	39.6	Chandler	13.4	CHP-2-24 p. 24
Brookfield Wind Park	75	Michigan	Huron	39.6	Fairhaven	51.5	CHP-2-24 p. 24
Echo Wind Park	112	Michigan	Huron	39.6	Grant	25.8	CHP-2-24 p. 24
Pheasant Run 1	75	Michigan	Huron	39.6	McKinley	22.1	CHP-2-24 p. 24
Thumb Wind Park	76	Michigan	Huron	39.6	Oliver	42	CHP-2-24 p. 24
		Michigan	Huron	39.6	Sigel	13	CHP-2-24 p. 24
		Michigan	Huron	39.6	Winsor	54.1	CHP-2-24 p. 24
Average County Pop/Sq.Mi. (Michigan Projects)	**101.5**						
Average Township Pop/Sq.Mi. (Michigan projects)	**30**						

Wind Project	MW Capacity	State	County	Pop/Sq.Mi.	Township	Pop/Sq.Mi.	Census Reference
Bent Tree Wind Farm	201	Minnesota	Freeborn	44.2	Manchester	11.9	CPH-2-25 p. 25
Bent Tree Wind Farm	201	Minnesota	Freeborn	44.2	Hartland	7.1	CPH-2-25 p. 25
Bent Tree Wind Farm	201	Minnesota	Freeborn	44.2	Bath	12.3	CPH-2-25 p. 25
Bent Tree Wind Farm	201	Minnesota	Freeborn	44.2	Freeborn	7.5	CPH-2-25 p. 25
Bent Tree Wind Farm	201	Minnesota	Freeborn	44.2	Bancroft	29.1	CPH-2-25 p. 25
Buffalo Ridge Wind Project	225	Minnesota	Lincoln	11	Lake Benton	7.3	CPH-2-25 p. 33
Buffalo Ridge Wind Project	225	Minnesota	Pipestone	20.6	Altona	3.6	CPH-2-25 p. 42
Buffalo Ridge Wind Project	225	Minnesota	Pipestone	20.6	Burke	6.1	CPH-2-25 p. 42
Buffalo Ridge Wind Project	225	Minnesota	Pipestone	20.6	Grange	5.6	CPH-2-25 p. 42
Buffalo Ridge Wind Project	225	Minnesota	Pipestone	20.6	Rock	5.1	CPH-2-25 p. 42
Elm Creek (I & II)	249	Minnesota	Jackson	14.6	Kimball	3.6	CPH-2-25 p. 29
Elm Creek (I & II)	249	Minnesota	Jackson	14.6	Enterprise	5.2	CPH-2-25 p. 29
Elm Creek (I & II)	249	Minnesota	Jackson	14.6	Wisconsin	6.6	CPH-2-25 p. 29
Elm Creek (I & II)	249	Minnesota	Martin	29.3	Elm Creek	5.4	CPH-2-25 p. 35
Elm Creek (I & II)	249	Minnesota	Martin	29.3	Cedar	6.4	CPH-2-25 p. 35
Fenton Wind Farm	206	Minnesota	Murray	12.4	Fenton	4.9	CPH-2-25 p. 38
Fenton Wind Farm	206	Minnesota	Murray	12.4	Moulton	5.8	CPH-2-25 p. 38
Fenton Wind Farm	206	Minnesota	Nobles	29.9	Wilmont	5.2	CPH-2-25 p. 39
Lakefield Wind Project	206	Minnesota	Jackson	14.6	Hunter	6.3	CPH-2-25 p. 29
Lakefield Wind Project	206	Minnesota	Jackson	14.6	Heron Lake	8.6	CPH-2-25 p. 29
Lakefield Wind Project	206	Minnesota	Jackson	14.6	Des Moines	7.5	CPH-2-25 p. 29

Wind Project	MW Capacity	State	County	Pop/Sq.Mi.	Township	Pop/Sq.Mi.	Census Reference
Lakefield Wind Project	206	Minnesota	Jackson	14.6	Belmont	6.1	CPH-2-25 p. 29
Nobles Wind Farm	201	Minnesota	Nobles	29.9	Larkin	5.3	CPH-2-25 p. 39
Nobles Wind Farm	201	Minnesota	Nobles	29.9	Summit Lake	9	CPH-2-25 p. 39
Nobles Wind Farm	201	Minnesota	Nobles	29.9	Olney	5.8	CPH-2-25 p. 39
Nobles Wind Farm	201	Minnesota	Nobles	29.9	Dewald	7.1	CPH-2-25 p. 39
Wind project name and township data shown in the following three line grouping for Mower County was received from a Mower County official, but the response did not itemize which of the provided projects were located in which of the provided townships, but only that these projects exist in Mower County and that they are located in the various townships listed. Therefore, the particular Mower County township listed in this grouping may not necessarily correspond to the particular Mower County wind project located on the same line in the table where the township is listed.							
Mower County Wind		Minnesota	Mower	55.1	Clayton	4.4	CPH-2-25 p. 37
Prairie Star Wind		Minnesota	Mower	55.1	Frankford	12.4	CPH-2-25 p. 37
Adams Wind		Minnesota	Mower	55.1	Grand Meadow	8.6	CPH-2-25 p. 37
Average County Pop/Sq.Mi. (Minnesota Projects)	**27.1**						
Average Township Pop/Sq.Mi. (Minnesota Projects)	**7.6**						

Wind Project	MW Capacity	State	County	Pop/Sq.Mi.	Township	Pop/Sq.Mi.	Census Reference
Blue Sky Green Field Wind Energy Center	145	Wisconsin	Fond du Lac	141.2	Marshfield	33.5	CPH-2-51 p. 23
Blue Sky Green Field Wind Energy Center	145	Wisconsin	Fond du Lac	141.2	Calumet	48.8	CPH-2-51 p. 22
Glacier Hills Wind Park	162	Wisconsin	Columbia	74.2	Randolph	22	CPH-2-51 p. 19
Glacier Hills Wind Park	162	Wisconsin	Columbia	74.2	Scott	25.4	CPH-2-51 p. 19
Forward Energy	129	Wisconsin	Dodge	101.4	Leroy	27.7	CPH-2-51 p. 20

Wind Project	MW Capacity	State	County	Pop/Sq.Mi.	Township	Pop/Sq.Mi.	Census Reference
Forward Energy	129	Wisconsin	Dodge	101.4	Lomira	33.3	CPH-2-51 p. 20
Forward Energy	129	Wisconsin	Fond du Lac	141.2	Byron	44.9	CPH-2-51 p. 22
Forward Energy	129	Wisconsin	Fond du Lac	141.2	Oakfield	19.8	CPH-2-51 p. 23
Cedar Ridge	68	Wisconsin	Fond du Lac	141.2	Eden	28.7	CPH-2-51 p. 23
Cedar Ridge	69	Wisconsin	Fond du Lac	141.2	Empire	97.3	CPH-2-51 p. 23
Butler Ridge	54	Wisconsin	Dodge	101.4	Herman	30.5	CPH-2-51 p. 20
Shirley Wind	20	Wisconsin	Brown	468.2	Glenmore	34.6	CPH-2-51 p. 16
Monfort Wind Farm	30	Wisconsin	Iowa	31.1	Eden	10.1	CPH-2-51 p. 25
Average County Pop/Sq.Mi. (Wisconsin Projects)			**163.2**				
Average Township Pop/Sq.Mi. (Wisconsin projects)			**35.1**				

Thirty years of North American wind energy acceptance research: What have we learned?

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Table of Contents

Abstract

Thirty years of North American research on public acceptance of wind energy has produced important insights, yet knowledge gaps remain. This review synthesizes the literature, revealing the following lessons learned. (1) North American support for wind has been consistently high. (2) The NIMBY explanation for resistance to wind development is invalid. (3) Socioeconomic impacts of wind development are strongly tied to acceptance. (4) Sound and visual impacts of wind facilities are strongly tied to annoyance and opposition, and ignoring these concerns can exacerbate conflict. (5) Environmental concerns matter, though less than other factors, and these concerns can both help and hinder wind development. (6) Issues of fairness, participation, and trust during the development process influence acceptance. (7) Distance from turbines affects other explanatory variables, but alone its influence is unclear. (8) Viewing opposition as something to be overcome prevents meaningful understandings and implementation of best practices. (9) Implementation of research findings into practice has been limited. The paper also identifies areas for future research on wind acceptance. With continued research efforts and a commitment toward implementing research findings into developer and policymaker practice, conflict and perceived injustices around proposed and existing wind energy facilities might be significantly lessened.

Keywords:
Wind energy; social acceptance; support and opposition; attitudes

1. Introduction

1.1 Background and Motivation

Over the last 30 years, wind energy in North America has evolved from a fringe, isolated, experimental concept into a mainstream and viable source of electricity, meeting about 5% of U.S. electricity demand (6% in Canada) and representing the largest source of new electric capacity additions in many recent years (CanWEA, 2016; Wiser & Bolinger, 2016). Wind energy is widely seen as an abundant electricity source with the potential to provide a wide range of environmental and social benefits (Intergovernmental Panel on Climate Change (IPCC), 2011). State/provincial-level mandates, federal incentives, declining wind energy costs, and relatively favorable economics have spurred the aggressive North American wind deployment of the past 10–15 years (Wiser & Bolinger, 2016).

This rapid growth in wind energy deployment will likely continue. In the United States, for example, recent market analysis suggests that annual wind power capacity additions are expected to continue rapidly in the coming five years (Wiser & Bolinger, 2016, p. 1) driven by expected lower prices (Wiser et al., 2016). Meanwhile, the U.S. Department of Energy's recent *Wind Vision Report,* which outlines pathways for wind energy to provide up to 35% of the nation's electrical demand by 2050, suggests that the "low hanging fruit" wind sites (those that have good wind resources and are close to loads and transmission, yet far from communities) have largely been developed, implying that future wind development likely will happen increasingly near communities. As such, the report underlines the need for a better understanding of the drivers of wind facility acceptance among affected communities (USDOE, 2015). This recommendation echoes the calls of numerous social scientists, who have suggested that successful implementation of U.S. wind projects relies on a deeper understanding of local stakeholders (e.g., Petrova, 2013).

Multiple facets of acceptance can impact the deployment of renewable energy projects. Wüstenhagen et al. (2007) point to three dimensions: *Sociopolitical acceptance* (acceptance of policymakers and key stakeholders), *market acceptance* (acceptance of investors and consumers), and *community acceptance* (pertaining to procedural justice, distributional justice, and trust). However, as Sovacool (2009, p. 4511) points out, these social, technical, economic, and political dimensions of acceptance all influence each other in an integrated, "pernicious tangle." For example, community acceptance of wind energy can affect market acceptance and vice versa. Indeed, this has been the case when local opposition has delayed or derailed proposed wind projects (Corscadden et al., 2012; Fast, 2015; Shaw et al., 2015). For years, debates around wind energy acceptance in North America focused on sociopolitical and market acceptance, pertaining largely to technological innovation, economic incentives, and impacts on the operations and resiliency of the electric grid, with less attention paid to societal impacts (Lantz & Flowers, 2011; Phadke, 2010). However, the rapid growth of North American wind energy has increased the footprint of wind developments, increasing local conflicts and bringing the issue of community acceptance to the forefront (Lantz & Flowers, 2011).

Despite broad public support for wind energy in general, local wind developments have been challenged by vocal opposition within host communities (Bidwell, 2013; Bohn & Lant, 2009; Lantz &

Flowers, 2011). In the early days of U.S. wind power, opposition and negative attitudes dismayed the industry, who expected local acceptance to be consistent with the favorable opinions toward wind power generally (Pasqualetti, 2001). Ever since opposition and negative attitudes emerged around some of the earliest experimental wind farms in California, researchers have tried to understand and characterize wind energy acceptance (see Bosley & Bosley, 1988; Pasqualetti & Butler, 1987; Thayer & Freeman, 1987). Community acceptance is now widely perceived by wind energy practitioners as a significant barrier to deployment of renewable energy (Lantz & Flowers, 2011).

Research interest in the public acceptance of wind energy has surged along with surging wind energy growth in North America. After three decades (1987–2017) of North American scholarship in this field, what have we learned, how can these lessons be applied, and what aspects should researchers focus on next?

This review synthesizes the findings from more than 100 papers on wind energy acceptance published over the past 30 years, with a specific focus on the North American set of literature.

1.2 Justification for North American Focus

The North American[1] body of wind energy acceptance literature merits this its own review, distinct from the literature of Europe (which represents a vast body of literature; see, e.g. Ellis & Ferraro (2016)) and other regions. Social acceptance is highly context dependent, and Canada and the United States share many aspects of culture, national energy policy and economics, population density, land use policy, wind energy development processes, and wind project ownership models that are distinct from Europe and the rest of the world.

North America currently represents nearly 1/5 of global installed wind energy capacity (Global Wind Energy Council (GWEC), 2017), and the growth rate of that capacity over the past 15 years is markedly faster in North America than in Europe. Since 2002, installed capacity has increased nearly twenty-fold in North America, compared to a seven-fold increase in Europe (AWEA, 2003; Global Wind Energy Council (GWEC), 2017). This rapid growth of land-based wind energy in North America may result in amplified impacts to host communities that should be studied independently from the European context, where onshore development has been slower in recent years. Similarly, the sluggish growth of offshore wind energy in North America may also indicate economic, environmental, cultural, and visual concerns that are unique from European experience and worthy of independent study. The first offshore wind farm in North America, a 30-Megawatt project, was installed in 2016, while over 12.6 Gigawatts had been installed in Europe by the end of the same year (Global Wind Energy Council (GWEC), 2017). The density of population in Europe, coupled with the density of land-based wind turbines, places a greater proportion of the European population in closer proximity to turbines compared to North America, which may conceivably influence aspects of acceptance.

North America is largely electricity independent with domestic reserves of coal, natural gas, uranium,

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[1] Very few studies from Mexico were found when preparing this review. The vast majority of papers reviewed herein focus on Canada and the United States.

hydropower, and other energy resources, whereas Europe is a net importer of fuels for electricity generation. These relatively cheap, domestic energy resources create steeper market competition and different economic conditions for wind deployment in North America compared to Europe. The European Union's Emissions Trading Scheme (EU ETS) represents an EU-wide, comprehensive climate policy; quite distinct from the state- or province-level energy and climate policies previously seen in North America. These are important differences in aspects of market and sociopolitical acceptance (both of which influence community acceptance, as described above) between North America and Europe.

Finally, community ownership and investment models are much less common in North America than in Europe (Bolinger, 2005; Ferguson-Martin & Hill, 2011; Sovacool & Ratan, 2012). In the United States, federal production incentives for wind energy have required a significant tax liability, tipping the scales toward large private developers of wind projects (Bolinger, 2005). Some studies have demonstrated that community ownership is correlated to higher support and more positive attitudes toward wind energy in Europe and other regions (Krohn & Damborg, 1999; Maruyama et al., 2007; Petrova, 2013; Warren & McFadyen, 2010). One may reasonably expect some differences in perceptions and acceptance of wind energy in North America in relation to the low level of community ownership in the region.

Despite this explicit geographic focus, a number of European papers are included in this review where those papers either introduce a novel concept or explanation that has since been studied in the North American context (e.g., place attachment theory), or point out broad aspects of the field of study of wind energy acceptance such as biases and limitations in previous research (see Section 4).

The following section outlines the methodological approach to reviewing the North American body of wind acceptance research. Section 3 provides a brief history of North American wind acceptance research to frame the papers discussed in this review. Section 4 discusses the limitations of previous research that have hindered meaningful understandings. Section 5 examines in detail the dominant explanations and overarching aspects of wind energy acceptance in the North American context. Section 6 provides a high-level summary of lessons learned from 30 years of research. Finally, Section 7 identifies gaps and areas where future research on the public acceptance of North American wind energy should focus.

2. Method of Literature Review

2.1 Selection of Publications to Review

The goal of this review was to broadly represent the body of research on wind energy acceptance undertaken in North America. Papers were initially solicited from a panel of five researchers in the field of wind energy acceptance in October, 2014. Additional papers were selected from internet searches using Google Scholar and Scopus[2] and from those cited in the papers (i.e. "snowballing"). Internet

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[2] See https://www.elsevier.com/solutions/scopus

searches focused on the most recent studies, 2014 and later, which were less well represented in the panel solicitation.

The solicitation and searches focused on papers written by authors with North American affiliations and/or research pertaining to North American wind facilities. Although the United States and Canada are well represented in this review, very few papers from Mexico were found in the literature. The review focuses on peer-reviewed journal articles, but some books are included as well as some grey literature, primarily in the form of government-sponsored reports. There was no restriction placed on the date range of the papers selected for review. The earliest relevant North American studies were published in 1987, with a clear growing trend in publications per year in this field through 2016 (see Figure 1). Selected papers represent a broad range of published years in order to capture the evolution in this body of literature over time.

Papers were selected to represent a broad array of themes and variables that are examined by their authors, as well as diversity in the research approach and methods employed. The array of acceptance-influencing variables examined in these papers is outlined in Table 1 of the Appendix. The research methods and approaches utilized by the studies examined in this review are outlined in the Appendix Table 2. These tables not only summarize the literature reviewed in this paper, but also serve to clearly illustrate particular explanatory variables and research methods that have been applied in the North American literature, thus elucidating gaps.

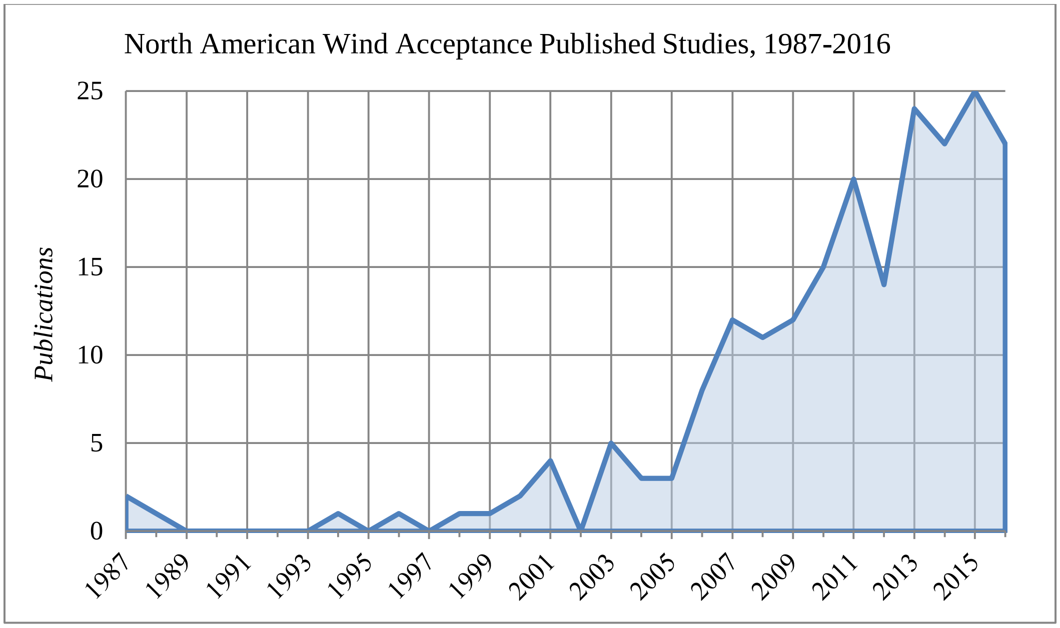

Figure 1: North American wind energy acceptance papers, 1987-2016. Data source: Scopus[3]

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[3] This search was conducted using the Scopus database on April 25, 2017 using the following search string: TITLE-ABS-KEY ("wind energy" AND (public OR acceptance)) AND (LIMIT-TO (AFFILCOUNTRY , "United States ") OR LIMIT-TO (AFFILCOUNTRY , "Canada ") OR LIMIT-TO (AFFILCOUNTRY , "Mexico "))

2.2 Data Collection, Coding, and Qualitative Analysis of Papers

As each paper was read, it was entered into a detailed summary matrix to catalog the year, research questions, methods, analysis techniques, location, wind energy statistics (if applicable), sample size, explanatory variables examined, major conclusions, and additional research recommendations of each study.

These data became the framework for qualitative content analysis of the papers, which relied on interpreting the results, discussions, conclusions, and significant explanatory variables identified in the papers. This qualitative analysis led to the creation of the major themes detailed in Section 5, as well as the lessons learned outlined in Section 6, and the recommendations for further research discussed in Section 7 of this paper.

For quantitative studies, themes were identified by explanatory variables that were found to have a statistically significant effect on attitudes, support, or opposition. However, in some cases, a major contribution of particular papers was to *not* find a statistically significant effect of certain variables. Those were also included in the broad themes of this review. Similarly with qualitative and mixed-methods studies, the themes emerging from interviews, focus groups, and content analyses were categorized among the dominant themes identified in the broader body of literature. Table 1 of Appendix A summarizes these major explanatory themes that emerged from the literature, and identifies which papers from this review address each theme.

From the body of papers selected for this review, six overarching themes explaining attitudes and/or support and opposition toward wind energy emerged. Within each theme, a number of sub-themes also existed. These explanatory themes (along with their sub-themes) are analyzed and summarized in detail in Section 5 of this paper. The results and major conclusions of each paper are examined and contrasted to each other within each theme or explanatory group. The purpose of this analysis was to identify those explanatory variables with either broad agreement or considerable disagreement among the studies reviewed. Agreement among numerous studies would represent lessons learned (Section 6), where considerable disagreement (or a lack of research) may indicate a need for further research and/or suggestions for new methodologies (Section 7).

3. A Brief History of North American Wind Energy Acceptance Research

Academic research seeking to understand the acceptance of North American wind energy began in earnest shortly after some of the first experimental wind farms were installed in California in the 1980s. Surveys by Pasqualetti and Butler (1987) and Thayer and Freeman (1987) found a range of opinions among nearby residents, with negative attitudes most closely correlated with feelings of aesthetic degradation and frustration about non-functioning (i.e., non-spinning) turbines. Drivers of negative attitudes cited by Bosley & Bosley (1988) include a lack of knowledge about wind energy's "maturity" among opponents along with a failure on the part of the wind industry to communicate properly with affected parties. Gipe (1995) dedicated a full chapter to turbine aesthetics and community acceptance in his book, *Wind Energy Comes of Age.* Gipe specifically addresses aesthetic design, turbine reliability, the pace and process of planning and development, the distribution of costs and benefits (i.e., compensation), and community ownership models as potential determinants of acceptance (Gipe, 1995). These early studies led the way for three decades of scholarship in the field of wind energy acceptance.

According to this literature, wind energy has been viewed favorably throughout North America over the past 30 years, with 70%–90% of those surveyed approving of wind energy generally (Bidwell, 2013; Klick & Smith, 2010; Vyas & Hurst, 2013) and that approval remaining high over time (Vyas & Hurst, 2013). Support also has been high among residents of communities where wind projects have been proposed but not yet built (Firestone et al., 2009; Firestone et al., 2012a; Mulvaney et al., 2013b). In studies of people near existing wind facilities, 70%–90% of respondents express positive or neutral attitudes (Baxter et al., 2013; Fergen & Jacquet, 2016; Mulvaney et al., 2013b; Pasqualetti & Butler, 1987; Petrova, 2014; Slattery et al., 2012). Nonetheless, the 10%–30% of individuals who do *not* support proposed wind developments or hold negative attitudes toward existing facilities—as well as the factors influencing those positions—are of strong interest to the research community. Many researchers also seek to identify ways to minimize negative factors from existing and future wind developments.

In any case, opposition to wind development and negative attitudes toward existing wind installations are normal, and they likely will exist as long as wind facilities exist. The same can be said about other large construction projects. Transmission lines, landfills, and parks are among the types of projects that have been opposed (Gipe, 1995), and some people even protested the location and appearance of the Statue of Liberty (Petrova, 2013). Every component of our current electrical system was the product of social negotiation and compromise, including over "17,000 conventional generators, 250,000 miles of high voltage transmission lines, thousands of substations," and much more (Sovacool, 2009, p. 4502).

The rich body of research on wind energy acceptance spans myriad disciplines, from psychology and health science to economics and political ecology. During the three decades of study that produced this literature, public acceptance of wind energy "has gone from a marginal and little studied point of discussion to be at the forefront of broader debates in the social sciences" (Fournis & Fortin, 2016, p. 1). The study of wind energy acceptance has evolved considerably over this time. While early studies were exploratory and anecdotal, the statistical rigor of analysis, the application of diverse methods, and the development of complex theoretical frameworks have all improved over time.

Accordingly, the North American literature has coalesced around the need to understand two primary dependent variables or outcomes of interest related to wind energy acceptance: level of support/opposition, and attitudes. This paper distinguishes these two variables by using the terms "support" and "opposition" when discussing *proposed* or *hypothetical* wind facilities (pre-construction) and "positive and negative attitudes" when discussing *existing* wind facilities (post-construction).[4] Each of these variables has a range (e.g., from support to oppose or from positive to negative) that are typically expressed in five-point Likert scales. The literature has similarly coalesced around a number of overarching explanatory variables, which influence or explain changes in these dependent variables. The major explanatory variables in the North American wind acceptance literature are detailed in Section 5.

4. Limitations of Previous North American Wind Acceptance Research

This section describes a number of fallacies, biases, and limitations that have pervaded previous North American wind acceptance research. In some cases, these biases and limitations have prevented meaningful understandings and obstructed implementation of research findings and recommendations among developers and policymakers. Where appropriate, recommendations for future research are noted briefly, which are later summarized in sections 6 and 7.

From early surveys of residents near California wind farms (Bosley & Bosley, 1988) until today, opposition and negative attitudes toward wind energy have commonly been described by developers, politicians, and researchers as not-in-my-backyard (NIMBY) resistance (Petrova, 2013). The NIMBY concept posits that individuals favor wind energy generally but not in their local context—not in their "backyard." NIMBY also has been studied for decades in the context of nuclear energy and other hazardous facilities as well as social facilities such as prisons and mental health institutions (Wolsink, 2000).

However, many researchers now agree that the NIMBY framework is overly simplistic and unable to explain the complex motivations, concerns, and perceptions that can lead to opposition and negative attitudes (Devine-Wright, 2005; Petrova, 2013). Firestone et al. (2012b) stress that NIMBY resistance may be a *result* of opposition, rather than an explanation of it. Moreover, the term is generally used pejoratively (Kempton et al., 2005). A study in Texas concludes that NIMBY is "politically inappropriate and can often lead to misunderstanding, adding little value to the decision-making process" (Swofford & Slattery, 2010, p. 2516).

Social science researchers now generally agree that the language and concept of NIMBY as an explanation for wind energy opposition should be abandoned altogether[5] (Devine-Wright, 2005; Petrova, 2013; Wolsink, 2006, 2012).

Another problem with the literature is positivist language toward wind energy, which some researchers

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[4] In some studies, residents near existing facilities are asked about their level of support for additional wind development in the area. The distinction between "attitudes" toward the existing facility and "support" for additional development still applies in these cases.

[5] Based on ample evidence that the NIMBY explanation is problematic and unhelpful, this paper discards the term and instead focuses on examining other proposed explanations and correlates of wind energy acceptance.

have argued may reduce the quality and reliability of research and may prevent meaningful understandings of public acceptance (Aitken, 2010; Ellis et al., 2007). European researchers such as Aitken (2010), Ellis (2007), and Taebi (2016) have criticized researchers who portray wind energy opponents as “deviant” and seek to understand opposition merely to “overcome” it, but this criticism of positivist research has not been highlighted or examined to the same degree by North American researchers. It has been suggested that instead of focusing on the reasons for negativity toward wind energy, some researchers have sought methods to ensure approval (Taebi, 2016). According to Ellis et al. (2007, p. 536), this positivist lens has led to “poor explanatory findings, which in turn has resulted in ineffective policy.” Songsore and Buzzelli (2014) stress that focusing only on mitigating resistance neglects important community concerns and may lead to negative consequences. Positivist language in the literature may include, for example:

- Statements that favor the needs of the wind industry over opponents, such as: “without public support in communities across the country, the industry's ability to build wind farms where it needs them may be hindered by nimbyism” (Klick & Smith, 2010, p. 1590)
- Statements that suggest opposition is a barrier that must be overcome and opponents are deviant, such as: “social barriers are blocking our way. That is to say, people are creating the problems, not technology” (Pasqualetti, 2011b, p. 202)
- Suggestions that the motivation of wind energy acceptance research is to help meet federal or state level renewable energy goals (e.g., Mulvaney et al., 2013)

Such positivist language has appeared regularly in the U.S. research to date (such as: Gipe, 1995; Klick & Smith, 2010; Olson-Hazboun et al., 2016; Pasqualetti, 2011b; Sovacool, 2009), but is less present in prominent Canadian research (such as: Baxter et al., 2013; Fast et al., 2016; Shaw et al., 2015; Walker et al., 2014b, 2014c), and rare in research rooted in humanistic geography (such as: Abbott, 2010; Phadke, 2013; Walker et al., 2014b), which tends to express more empathy toward affected communities. Researchers should cautiously avoid a positivist research lens.

Many North American wind energy acceptance studies have focused on hypothetical or proposed wind facilities, rather than existing facilities. Although asking individuals about their opinions toward hypothetical or proposed wind facilities can help answer certain research questions (e.g., about facilities, like offshore U.S. wind farms, that do not yet exist), these studies cannot reflect the unique feelings and experiences of residents living near existing turbines. Moreover, many studies around existing wind projects have not adequately examined the population living nearest to the turbines by oversampling and/or isolating the nearest residents for unique analyses (such as: Baxter et al., 2013; Bidwell, 2013; Fergen & Jacquet, 2016; Groth & Vogt, 2014; Olson-Hazboun et al., 2016; Pasqualetti & Butler, 1987; Petrova, 2014; Slattery et al., 2012; Thayer & Freeman, 1987). As such, numerous researchers have called for research focusing on residents closest to wind turbines (Hoen et al., 2011; Walker et al., 2014a). It is especially important that this group be represented in acceptance research, because it is most likely to be affected by wind facilities.

The vast majority of North American studies focus on only one or a few locations or wind facilities, so results cannot be generalized to the wider population living near wind turbines (e.g. Baxter et al., 2013;

Bidwell, 2013; Firestone & Kempton, 2007; Firestone et al., 2012b; Groothuis et al., 2008; Groth & Vogt, 2014; Olson-Hazboun et al., 2016; Pasqualetti & Butler, 1987; Petrova, 2014; Slattery et al., 2012; Thayer & Freeman, 1987). Some of these studies have used convenience samples rather than robust random samples, further limiting their external validity (e.g. Landry et al., 2012; Mulvaney et al., 2013b; Walker et al., 2014c). Fast and Mabee (2015, p. 27) suggest that this qualitative, case-study nature of wind acceptance research "does not translate well to conventional policy making." The dominance of these discrete case studies with poor comparability between them has recently led some European researchers to question whether wind acceptance research is "running out of steam" (Ellis & Ferraro, 2017).

There are considerable challenges and costs to developing and deploying research that is broadly representative across large regions like North America, making such studies out of reach for most researchers. Case studies may still add considerable insights and value in the North American context, but the value of these studies could be compounded through comparison. Future research might attempt to standardize some survey items and protocols in order to enable comparison of data across multiple case studies.

Nationwide surveys of wind acceptance in the United States and Canada ask only very broad questions, for example, about levels of support for wind energy generally. These broad surveys typically find high levels of support and positive attitudes (Ipsos, 2010; Leiserowitz et al., 2014; Vyas & Hurst, 2013), but they tell us little about *why* respondents feel the way they do. Some researchers have even called into question the validity of such general opinion polls (Aitken, 2010).

It would be useful to examine wind energy acceptance in concert with acceptance of other energy sources—like coal, nuclear, natural gas, and solar—but this has rarely been done. A notable exception is the work of Jeffery Jacquet, whose studies examine attitudes toward and perceived impacts of wind energy and natural gas developments, finding more polarized and negative attitudes and larger perceived impacts (both negative and positive) related to natural gas developments (Jacquet, 2012; Jacquet & Stedman, 2013).

The successful implementation of thirty years of research findings into developer and policymaker practice over the past has also been limited. As Zaunbrecher and Ziefle (2016, p. 312) state, "many factors that influence the social acceptance of wind power plants are already known. However, a conceptual framework for wind power plant planning that integrates these factors as well as the method of assessing them is still missing." Frameworks for wind project planning that increase community engagement and reduce conflict, such as those developed by Petrova (2016) and Jami & Walsh (2017), could continue to be developed and examined.

Despite these limitations, the North American wind acceptance literature has contributed significantly to the state of knowledge, and has evolved iteratively over the past 30 years, with improving rigor of research over time. The literature's major findings and contributions are summarized in the following section.

5. Overarching Aspects and Explanatory Variables in North American Literature

The North American literature reveals two primary dependent variables related to wind energy acceptance: level of support/opposition and attitudes among residents living near proposed or existing wind facilities. Among the explanatory variables that researchers correlate to those dependent variables, six overarching themes emerge: (1) socioeconomic aspects (including compensation); (2) sound annoyance and health risk perceptions; (3) visual/landscape aspects, annoyance, and place attachment; (4) environmental concerns and attitudes; (5) perceptions of planning process, fairness, and trust; and (6) distance from turbines (proximity hypothesis). Each theme is detailed below.

5.1 Socioeconomic Aspects

Individuals express a great deal of positive and negative concern over the socioeconomic aspects of wind facilities. Some studies find anticipated economic effects to be the variable most strongly influencing support or opposition to proposed wind developments as well as positive or negative attitudes toward existing sites (Bidwell, 2013; Brannstrom et al., 2011; Slattery et al., 2012; Songsore & Buzzelli, 2015).

5.1.1 Positive economic aspects

Positive economic aspects of wind energy development include rural economic development (Mulvaney et al., 2013b) including creation of jobs and other economic opportunities (Slattery et al., 2012), local tax revenue and/or lower tax rates for individuals (Slattery et al., 2012), increased tourism (Groth & Vogt, 2014), reduced electricity rates (Baxter et al., 2013) and landowner compensation (Jacquet, 2012). Landowner compensation, however, is not a universally positive socioeconomic impact for individuals living near turbines. It may create perceptions of “winners” and “losers” (Firestone et al., 2012b) and increase intra-community conflict (Baxter et al., 2013; Walker et al., 2014b). Compensation can even be seen as a form of bribery (Gipe, 1995). Having some form of compensation for nearby residents that are not hosting turbines on their land may lesson conflict and notions of winners and losers. For example, non-monetary, non-individual compensation such as the creation of dedicated wildlife habitats or support of community projects was supported by non-hosting community members in one study (Groth & Vogt, 2014). Other research suggests that non-hosting community members prefer public compensation over private compensation (García et al., 2016). Another form of compensation that has been examined is community investment in or ownership of wind facilities. Local ownership enables more equitable distribution of financial benefits as well as a higher degree of participation and influence in the development of a wind facility (Fast et al., 2016). This model has been shown to increase support in the European context, but little evidence exists in the North American context where community ownership remains rare (Bolinger, 2005; Ferguson-Martin & Hill, 2011; Sovacool & Ratan, 2012). In general, more research is needed to understand appropriate and acceptable compensation mechanisms for individuals and communities.

5.1.2 Negative economic aspects

Perceived negative socioeconomic impacts include reduced property values (Abbott, 2010; Firestone & Kempton, 2007; Hoen et al., 2015), decreased tourism (Landry et al., 2012; Lilley et al., 2010; Lutzeyer, 2013), increased traffic (Slattery et al., 2012), exacerbating economic inequality (Walker et al., 2014b, 2014c), impacts to fishing and other recreational opportunities (Firestone et al., 2009), and increased electricity rates (Baxter et al., 2013). Impacts on electricity rates are seen as a two-sided coin, with supporters citing reduced rates and opponents citing increased rates (Firestone et al., 2012a). Although nationwide and state-level studies in the United States have not found evidence of consistent, measurable, or significant reductions in home values near operating wind facilities (Hoen & Atkinson-Palombo, 2016; Hoen et al., 2015; Lang et al., 2014), the *perception* or belief of property value impacts may still affect acceptance of wind (Abbott, 2010; Walker et al., 2014a). Additionally, there is evidence that home-value effects might exist in the U.S. (Heintzelman & Tuttle, 2012) and Canadian (Fast et al., 2015) contexts, and there is growing evidence that effects exist in the European context (e.g. Dröes & Koster, 2016; Gibbons, 2015; Jensen et al., 2014). More research in this area could not only untangle conflicting results, but also increase understanding of how perceptions of property value impacts influence acceptance.

5.1.3 Distributional justice

The distribution of the costs and benefits of wind energy developments, broadly referred to as *distributional justice*, has been widely studied in the literature. Survey respondents consistently express concern that the energy and economic benefits produced from local wind facilities do not stay local and benefit local residents (Baxter et al., 2013; Groth & Vogt, 2014). Some studies have shown angst and opposition toward multinational corporate wind developers (Pasqualetti, 2011a; Petrova, 2013), and Firestone and Kempton (2007) demonstrate that support would increase for a proposed wind facility if it were being developed by the local government, rather than a private developer. The inability of local community members to invest or share ownership in wind energy developments has been cited as a factor in negative attitudes (Songsore & Buzzelli, 2015).

Unfair distribution of costs and benefits may lead to intra-community and/or rural-urban conflicts (Hirsh & Sovacool, 2013; Larson & Krannich, 2016; Pasqualetti, 2000; Phadke, 2013; Rule, 2014; Sovacool, 2009; Walker et al., 2014c) or injustices toward indigenous communities (Huesca-Pérez et al., 2016). Phadke (2013, p. 248) summarizes this conflict: “Rural communities at the forefront of new energy development are asking why they are disproportionately being asked to carry the weight of the new carbon economy while urban residents continue their conspicuous use of energy.” Rural residents may also feel exploited by urban, multinational, corporate project developers seeking profits over public welfare (Petrova, 2013; Sovacool, 2009). Thus, some individuals who oppose or hold negative attitudes toward wind facilities may be fighting against a feeling of injustice as they find themselves on the front lines of development impacts while still on the margins of politics and economic opportunity. On the other hand, rural-urban conflicts may also propagate when the local, rural residents *support* the wind facility. Sovacool (2009, p. 4510) suggests that, in some cases, “rural [longstanding] residents want renewable power projects for their own use, as a vehicle for economic development, and resent what seems like meddling by urban [newly arrived] residents intent on preserving the countryside for its scenic and recreational value."

Perceived socioeconomic impacts are at the forefront of concerns for many individuals living near existing and proposed wind facilities, but those perceived impacts and the ways they influence acceptance are complex. More research is needed to understand inter- and intra-community conflicts, the effects of and community responses toward compensation mechanisms, and the relationships between perceived economic impacts and perceived fairness of planning processes and outcomes.

5.2 Sound Annoyance and Health Risk Perceptions

5.2.1 Annoyance from wind turbine sound

Some studies have correlated turbine sound with *annoyance*, which may be associated with sleep disturbance, negative emotions, or other health-related effects (Knopper & Ollson, 2011; Knopper et al., 2014; Michaud et al., 2016a). The annoyance experienced by people living near utility-scale wind facilities is correlated to more negative attitudes (Fast et al., 2016; Firestone et al., 2015). This annoyance, however, may be more strongly correlated to other characteristics rather than wind turbine sounds (McCunney et al., 2014). In Europe, Pedersen & Waye (2004), showed that residents' level of annoyance with wind turbine sound is strongly influenced by their level of annoyance with the visual impact of turbines (discussed in section 5.3.1), yielding higher annoyance with turbine sound compared with dose-response curves from other, non-turbine sound emissions, such as transportation noise. This result deserves further study in the North American context.

Some research has demonstrated that annoyance and complaints decline with increased distance from turbines (Kaliski & Neeraj, 2013; Nissenbaum et al., 2012), but there is no general consensus about the setback distance required to minimize or mitigate annoyance (Nissenbaum et al., 2012) as distance is just one component of how sound from turbines propagates to nearby residents. Accordingly, researchers (and stakeholders in general) often rely on a sound-specific threshold to reduce annoyance and stress impacts and concerns from local residents, which is commonly 40-45 dBA[6] (Knopper & Ollson, 2011; Knopper et al., 2014; Paller, 2014; Phadke, 2013). The World Health Organization recommended a maximum of 45 dBA outside of homes during night hours (World Health Organization, 1999), but that recommendation was revised for the European Union in 2009 to 40 dBA (World Health Organization, 2009). This sound level has been compared to the sound level of a quiet office, library, a computer, or a refrigerator in a nearby room[7]. In a recent comprehensive study of measured wind turbine sound levels and reported health effects, turbine noise reached a maximum of 46 dBA and a mean of 35.6 dBA for 1,238 residents living between 0.25 – 11.22 kilometers from operational wind turbines in Canada (Michaud et al., 2016b).

Although sound levels comparable to a quiet office or library may not be annoying to most people, studies have suggested that wind turbine noise is considered annoying at much lower sound levels than those causing annoyance from other sources (Janssen et al., 2011). Some recent research has attributed

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[6] dBA = A-weighted decibels, a measure of loudness as perceived by the human ear. Measurements are typically average nighttime levels outside homes, and do not include ambient noise.

[7] For example dBA comparisons, see e.g., http://www.rlcraigco.com/pdf/dba-comparison.pdf

this to the amplitude modulation (i.e. swishing or thumping) of turbine sounds (Yoon et al., 2016), however this has not been rigorously examined in the North American context.

5.2.2 Health effects of wind turbine sound

Recent epidemiological research concludes that wind turbine sound and infrasound[8] are not directly related to adverse human health effects (Knopper & Ollson, 2011; Knopper et al., 2014; Michaud et al., 2016a) or sleep quality (Michaud et al., 2016b). Some research attributes wind-related health symptoms to the "nocebo" hypothesis, in which the *expectation* of negative health effects influences symptoms experienced (Knopper et al., 2014).

Nonetheless, the *perception* of health risk clearly reduces support for wind facilities (Baxter et al., 2013; Magari et al., 2014), and some wind opponents may feel that potential health risks are not adequately addressed (Songsore & Buzzelli, 2014). Walker et al. (2014c, p. 1) suggest a move beyond debating "whether or not 'annoyance' represents a 'health impact' and instead focus[ing] on ways to minimize … feelings of threat and stress at the community level." Similarly, Fast et al. (2016, p. 3) conclude that "rather than dismissing health claims as groundless or inconsequential, policy-makers should take a precautionary approach so as to more thoroughly address the factors that contribute to frustration on the part of host communities." If community concerns and expectations regarding sound and health impacts are not adequately addressed, a portion of the population may remain annoyed even after noise limits are enforced (Knopper et al., 2014).

Although there is a demonstrated correlation between wind facility sound, annoyance, and negative attitudes, more research is needed to understand these relationships. Topics that must be explored include measured (or modeled) sound and reported annoyance levels; types of sounds that are particularly annoying; the relationships among sound, annoyance, and respondents' distance from turbines; and the influence of other variables such as visual annoyance, place attachment, procedural fairness, and respondent characteristics.

5.3 Visual/Landscape Aspects, Annoyance, and Place Attachment

Visual impacts and landscape change are some of the most frequently cited correlates to reduced support of proposed wind projects and negative attitudes toward existing wind facilities. In general, visual and landscape concerns relate to a desire of communities to protect local landscape quality and identity in the face of change (Phadke, 2010).

5.3.1 Aesthetics and Annoyance

Numerous studies have indicated that the diminution of scenic beauty due to existing or proposed wind facilities may contribute to annoyance and is often linked to negative attitudes or reduced support (Bosley & Bosley, 1988; Bush & Hoagland, 2016; Gipe, 1993, 1995; Jacquet & Stedman, 2013; Pasqualetti & Butler, 1987; Pasqualetti et al., 2002; Phadke, 2010; Rule, 2014). Visual annoyance may

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[8] Infrasound is sound at frequencies lower than 20 Hz, which may be emitted by wind turbines as well as a number of other sources.

also result from “shadow flicker” created near turbines as sunlight passes through the blades of wind turbine in motion (Rule, 2014). Knopper & Ollson (2011) conclude that annoyance and self-reported health effects are more strongly related to visual impacts than to sound from wind facilities. Some researchers have suggested guidelines or best-practices for minimizing visual impacts of wind developments (Apostol et al., 2016; Pasqualetti et al., 2002); visual impact guidelines have also been suggested by U.S. (National Academy of Sciences (NAS), 2007; Sullivan et al., 2012) and Canadian (BC Ministry of Forests, 2016) government organizations.

New wind development in North America now routinely includes some form of visual impact assessment, typically in the form of computer-generated visual simulations of what a wind facility may look like from various vantage points (Apostol et al., 2016; Phadke, 2010). Phadke (2010, p. 17) argued that the visualizations created by wind energy developers and project opponents alike are an “immature policy craft”, are inherently political, and encoded with cultural values. As such, they may further polarize opinions rather than providing useful information to community stakeholders. However, Apostol et al. (2016) suggest useful guidance and techniques to improve such visualizations and enhance their usefulness.

Negative attitudes stemming from the visual impacts of wind turbines may not occur simply because people dislike how turbines look; people also have become accustomed to an electricity system that is essentially “invisible” to consumers owing to centralized infrastructure typically sited far from population centers (Pasqualetti, 2000; Sovacool, 2009). As Sovacool (2009, p. 4509) states, “the physical ‘removal’ of power stations from most cities and neighborhoods also ‘removes’ them from the minds of most Americans, and contributes to public apathy and misunderstanding.” Until recently, “electric generators were usually built in obscure locations, perceptible only to a few people. But wind turbines, by their very nature, require a highly dispersed and visible distribution, often in attractive and unspoiled areas” (Hirsh & Sovacool, 2013, p. 724).

On the other hand, visual impacts are not universally negative; there is some evidence for positive visual and symbolic perceptions from wind facilities (e.g., Brannstrom et al., 2011; Firestone et al., 2015; Mulvaney et al., 2013a; Phadke, 2010).

The rotational motion of wind turbines has been another topic of study. Early studies found that perceptions that turbines were “unreliable” or often not operating were correlated to negative attitudes and concerns about tax fraud (Gipe, 1993; Pasqualetti & Butler, 1987; Thayer & Freeman, 1987). More recently, Fergen and Jacquet (2016) found that respondents believed nearby turbines were more beautiful when the turbines were in motion, which they attribute to notions of economic productivity of turbines in motion compared to lost economic opportunity of motionless turbines.

5.3.2 Visual impacts and economics

Some researchers have highlighted visual impacts from wind turbines in choice experiments or other economic modeling techniques. For example, some property value impact studies use distance and views of the turbines as correlates (e.g. Hoen et al., 2011; Jensen et al., 2014). Some residents may be willing to pay to minimize the perceived negative visual impacts of proposed wind facilities (Boatwright, 2013; Groothuis et al., 2008; Krueger et al., 2011; Pasqualetti, 2001). Visual impacts have even been framed as a property-rights infringement in some cases (Abbott, 2010).

5.3.3 Place Attachment

Threats to *place attachment*—an emotional bond between individuals and the familiar locations they inhabit—are highlighted as a correlate in European literature (Devine-Wright, 2009; Devine-Wright & Howes, 2010). Under the place attachment theory, landscape impacts extend beyond aesthetics into the identities, connections, and meanings that individuals form with a particular location (Devine-Wright, 2009). Some North American studies also emphasize the role of place attachment in influencing wind energy acceptance (Bidwell, 2013; Fast & Mabee, 2015; Firestone et al., 2009), but Jacquet and Stedman (2013) found that place meanings seemed to have little or no association with acceptance of wind development in their Pennsylvania study. Future research in North America should continue to examine the influence of place attachment on acceptance.

Visual impacts are a widely studied, well-documented correlate to wind energy acceptance. Requiring further study, however, are the extent to which visual impacts influence other explanatory variables and vice versa (e.g., sound); the mechanisms behind *positive* visual perceptions; the effects of distance and physical geography on visual annoyance; the effect of different degrees of visual impacts (such as seeing the full sweep of turbine blades from the home vs. only a portion of the turbine); the frequency individuals see the turbines; and the role of planning process fairness and/or participation in diminishing or mitigating visual annoyance.

5.4 Environmental Concerns and Attitudes

Numerous researchers have noted that, in wind power siting debates, both supporters and opponents base their arguments on environmental concerns. These so-called “green vs. green” debates typically revolve around local environmental harms (e.g., wildlife, landscape, and noise impacts) versus regional or global benefits (e.g., climate change mitigation and air pollution reduction) (Firestone et al., 2009; Warren et al., 2005). As such, some studies have found pro-environmental beliefs and values to correlate positively with support for wind energy (Larson & Krannich, 2016; Mulvaney et al., 2013b), while others have found the opposite (Fergen & Jacquet, 2016). Research has also shown that environmental beliefs may correlate to support for wind energy broadly, but that support may not exist when the same individuals are asked about local wind energy development (Larson & Krannich, 2016). In some cases, individuals with stronger environmental attitudes may prioritize the conservation of “natural” landscape over the benefits of renewable energy (Fergen & Jacquet, 2016). Abbott (2010, p. 971) concludes that these multiple conservation priorities perpetuate environmental conflicts in local contexts.

5.4.1 Wildlife concerns

Since the earliest wind facilities in North America began operation, the potential threats of wind energy to wildlife, particularly birds and bats, have been of significant concern. A 2013 study estimated that between 140,000 and 328,000 birds are killed annually by collisions with wind turbine towers in the contiguous United States (Loss et al., 2013). This is a notable impact that may reduce support for wind energy in some individuals. However, Sovacool (2013) estimates that wind energy kills approximately 13 times fewer birds than fossil fueled power plants per kilowatt-hour of electricity generated. Similarly, a recent Canadian study found that avian mortality due to wind turbines was relatively small compared to other sources of human-influenced avian mortality (Zimmerling et al., 2013). These factors may induce some individuals to prefer the avian impacts of wind energy in comparison to alternatives (thus increasing support). Perhaps due to these conflicting considerations, previous research does not demonstrate a clear influence of wildlife impacts on onshore wind energy acceptance. Summary statistics have shown between 18-24% of local residents consider onshore wind turbines dangerous to wildlife (Mulvaney et al., 2013a; Slattery et al., 2012; Thayer & Freeman, 1987), and few studies have found this concern to statistically affect acceptance (e.g., Larson & Krannich, 2016).

Experience from the Cape Wind project suggests that wildlife concerns may significantly influence acceptance of *offshore* wind energy. Firestone et al. (2012a), for example, found that 48% of respondents believed Cape Wind would cause harm to bird life, and 44% thought it would harm marine life (those percentages decreased slightly in a repeat survey in 2009). Firestone and Kempton (2007) reported that if Cape Wind were found to harm marine or bird life, the majority of respondents would be less likely to support the project. In their book on Cape Wind, Williams and Whitcomb (2007) also emphasize the role of perceived impacts to birds, fish, and whales in shaping public opinion.

5.4.2 Climate change concerns

Wind energy's potential to mitigate climate change is a benefit often cited by supporters (Petrova, 2013), but concern for climate change alone does not fully explain support for wind. Accordingly, efforts to encourage support by emphasizing climate benefits may be met with indifference (Bidwell, 2015; Firestone et al., 2009; Petrova, 2016; Swofford & Slattery, 2010). Olson-Hazboun et al. (2016, p. 168) further suggest that emphasizing environmental and climate benefits may actually *increase* opposition in some contexts owing to the politically polarizing nature of such topics; they conclude that "the framing of renewable energy as an environmental issue could have unintended and adverse effects in certain social and political contexts." Other research has found that even people who are unconcerned about the environment or the use of fossil fuels may strongly support wind energy development based on potential economic opportunities (Slattery et al., 2012).

Overall, a number of researchers have found that support for wind energy is less correlated to environmental beliefs than to other factors such as economic and landscape impacts (Olson-Hazboun et al., 2016). Nonetheless environmental concerns clearly play a role in attitude formation for many individuals living near turbines, and more research could add nuance to the perceived environmental trade-offs of wind energy. Future work should continue to examine the role of environmental motivations for wind energy attitudes in different socio-political contexts.

5.5 Perceptions of Planning Process, Fairness, and Trust

The processes around wind project planning and development can significantly affect public acceptance (Firestone et al., 2012b), and a lack of opportunity for local residents to engage meaningfully in the planning process may reduce support or increase local conflict (Bohn & Lant, 2009; Huesca-Pérez et al., 2016; Phadke, 2011). In some wind development models, local citizens have been entirely removed from the planning and design of wind developments (Phadke, 2013). This may lead to feelings of injustice among local residents, who perceive that "government and corporate decision-making … takes place in faraway boardrooms disconnected from the people and landscapes that will be directly affected" (Phadke, 2013, p. 247). This perception of injustice may be especially severe among already disadvantaged communities (Huesca-Pérez et al., 2016).

A more participatory, collaborative planning process may reduce conflict and promote positive community outcomes (Groth & Vogt, 2014; Jami & Walsh, 2017; Songsore & Buzzelli, 2015; Walker et al., 2014c). Some scholars have suggested moving away from a "decide-announce-defend" model of wind facility planning toward a more collaborative, "consult-consider-modify-proceed" process (Phadke, 2013, p. 250). Indeed, Jacquet (2015) found that landowners participating and negotiating in the development process were better informed and more supportive than non-participating landowners. Some researchers, however, have demonstrated significant barriers to genuinely participatory, consensus-based planning processes, which may prevent widespread implementation of such strategies (Jami & Walsh, 2014). The numerous calls from researchers to increase public participation rarely include detail on how to implement participatory methods or measure their success (Bidwell, 2016b). In response to this need, a recent paper developed a recommended framework for meaningful community engagement and outlined a number of suggested strategies to increase public participation and reach consensus, including: early involvement of the community, being available, proactive, and present within the community, building relationships and trust, and offering financial investment in the project to the local community (Jami & Walsh, 2017). Nonetheless, questions still remain about how and when to engage the public and encourage participation in the planning process. Despite the challenges, it is seen as counterproductive to exclude participation based on the assumption that local community members lack the necessary information to make informed decisions (Petrova, 2016).

A planning process perceived as "fair" can lead to greater toleration of the outcome, even if it does not fully satisfy all stakeholders (Firestone et al., 2012b), whereas processes perceived as "unfair" can result in conflict, damaged relationships, and divided communities (Fast et al., 2016). However, greater toleration is not necessarily synonymous with support or "successful coexistence" (Songsore & Buzzelli, 2014). In other words, individuals may tolerate an outcome they perceive as fair, even if they did not get exactly what they wanted. Owing to this distinction, some researchers have begun to study support and toleration as separate dependent variables (Petrova, 2013).

The perceived fairness of the planning process is linked to *trust* between the local community and the project developers, and some researchers consider this trust important for project support (Dwyer, 2016; Fast & Mabee, 2015). Shaw et al. (2015) conclude that public trust has been eroded by governments that have not effectively engaged communities in fair decision-making processes. Aitken (2010, p. 1840) stresses that a pro-wind bias among developers and policymakers can undermine trust among stakeholders: "In order for this trust to be meaningful it cannot be conceived as a means to a particular end—i.e. less opposition and more wind farms."

Although numerous studies have shown correlations among perceived inclusiveness, fairness, trust, toleration, and support, more research is needed to understand when and how actually to *implement* more collaborative, democratic planning processes. Future research should also further examine the relationships between perceived procedural justice and socioeconomic impacts of wind development.

5.6 Distance from Turbines (Proximity Hypothesis)

Since the earliest studies on this topic, researchers have consistently examined the hypothesis that those living closest to turbines will have the most negative attitudes about the local wind facility. These studies, however, have produced no clear consensus. Some studies confirm the notion that positive attitudes increase with distance from the nearest turbine (Swofford & Slattery, 2010; Thayer & Freeman, 1987), while others show the exact opposite: that those living nearest turbines have more positive attitudes and are less concerned about potential negative impacts of the turbines (Baxter et al., 2013; Groth & Vogt, 2014; Warren et al., 2005). However, it is unclear whether such results adequately account for confounding variables, such as landowner compensation and other economic benefits accruing to nearby residents.

Olson-Hazboun et al. (2016) studied a different, related variable in addition to distance from the nearest turbine: how frequently respondents see (or expect to see) wind turbines, which they call "visual accessibility." These authors found no significant relationship between distance and attitudes toward the wind facility, but they did find that residents who see wind turbines more frequently were less likely to express positive attitudes toward the facility. Other studies have proposed that impacts from wind facilities may be cumulative, increasing with the size of turbines, the number of turbines visible, and the clustering of turbines (Petrova, 2013; Walker et al., 2014c). However, some European studies have not found a significant correlation between the number of turbines and negative attitudes (Krohn & Damborg, 1999; Pohl et al., 2012). Questions around cumulative impacts and visual accessibility merit additional study in the North American context.

Some researchers have hypothesized that, over time, individuals will "self-sort," as those with more positive attitudes move closer to turbines and those with more negative attitudes move away (Hoen et al., 2015; Tiebout, 1956). This effect, however, has not been rigorously examined.

Although many researchers have found a correlation between distance from an individual to the nearest turbine and attitudes toward wind energy, the direction and strength of that correlation remains in question, as does the extent to which regional, demographic, or other factors may influence this correlation. More research is also needed to understand relationships between distance and other correlates to acceptance, such as sound and visual impacts.

5.7 Other Proposed Correlates of Acceptance

Aside from the six dominant themes discussed in the preceding sections, the literature identifies a number of other potential correlates of wind energy acceptance. Some researchers have proposed that a lack of knowledge about energy generally or wind energy specifically may explain opposition or negative attitudes (Bosley & Bosley, 1988; Bush & Hoagland, 2016; Klick & Smith, 2010; Sovacool, 2009), but this “information deficit” explanation has been largely discredited. Opponents and those with negative attitudes are not ignorant of wind energy facts (Fast, 2015), and high levels of knowledge about energy do not necessarily correlate with support or positive attitudes (Baxter et al., 2013). On the other hand, Bidwell (2016a) did find a relationship between an informational intervention and increased support, and suggests that the information deficit model should not be dismissed.

Demographic data are also routinely collected and examined as possible correlates to wind energy acceptance in survey research. However, throughout the literature, demographic variables such as gender, income, and education level do little to explain variation in wind energy support or attitudes. Where reported, the effects of demographic variables on acceptance are typically not statistically significant (e.g., Firestone et al., 2015; Jacquet & Stedman, 2013; Mulvaney et al., 2013b).

Other proposed explanations for acceptance include concerns about dependence on foreign energy sources (Firestone et al., 2009), personal and moral values (Bidwell, 2013, 2015), attitudes toward local or federal government policy (Fast & Mabee, 2015; Petrova, 2014; Songsore & Buzzelli, 2014), and the degree to which expectations about a development are met (Fergen & Jacquet, 2016).

Many of these additional variables may relate to and be influenced by the six major themes previously discussed. In addition to clarifying the influence of the six major themes, future research should explore the influence of these other variables.

6. Lessons learned in 30 years of wind acceptance studies

Over the past three decades, scholars have substantially advanced the state of knowledge about wind energy acceptance in North America. Each new study has added evidence to existing hypotheses, proposed new hypotheses, presented new methods for engaging stakeholders in research, used new methods for data analysis, and/or incorporated new geographic areas under the umbrella of research. The studies have collected data spanning the period before any local development to well after the wind facilities began operating. Drawing from the sections above, the lessons learned over the past 30 years are summarized here:

Overall, support is high, and attitudes are largely positive. The North American literature consistently finds favorable views of wind energy; 70%–90% of North Americans approve of wind energy generally, and support has been high for specific existing and proposed wind facilities as well.

Researchers should cautiously avoid a positivist research lens. Viewing opposition merely as something to be *overcome* reduces the quality of research and prevents meaningful understandings and implementation of best practices. The motivation of wind energy acceptance research should not be exclusively to ensure approval of wind energy developments.

NIMBY is invalid. The NIMBY explanation has been widely discredited as simplistic, pejorative, politically inappropriate, and unhelpful as a framework to explain public attitudes toward wind facilities both before and after they are built. Nonetheless, use of the term persists among the wind industry, policymakers, even researchers.

Incorporating research into practice has lagged. Research over the past 30 years has produced many important insights, but these lessons have been slow to transition into practice among developers and policymakers.

Perceptions of turbine performance and reliability matter. Early studies revealed widespread concerns about turbine performance and reliability. More recently, studies have found a preference for turbines in motion compared to static turbines.

Demographics do not explain much. Throughout the literature, demographic variables such as gender, income, and education level do little to explain variation in wind energy attitudes; some studies have shown contradictory evidence related to these variables.

Socioeconomic impacts are very important. Local stakeholders are concerned with various socioeconomic impacts, and some researchers have found socioeconomic concerns to be paramount among local residents. In general, those living near wind facilities want benefits that stay in the local community, and they feel a sense of injustice about bearing the burden of costs when consumption of and profits related to the power are enjoyed elsewhere.

Sound and visual impacts are strongly tied to annoyance and opposition. Annoyance and opposition related to actual or expected sound and visual impacts are well documented throughout the literature. In some cases, annoyance and other impacts are ignored, downplayed, or assumed to be absent or inconsequential by developers and policymakers, which may exacerbate conflict and distrust among community members.

Environmental concerns matter, though perhaps less than other factors. Environmental concerns correlate with wind energy acceptance, but the strength of that correlation may be lower than that of other factors like socioeconomic impacts. Also, the direction of the correlation remains unclear.

Process fairness, participation, and trust can influence acceptance. A planning process that is perceived as “fair” can lead to greater toleration of the outcome, even if it does not fully satisfy all stakeholders. More participatory processes may increase trust and support, and ongoing post-construction community stewardship should be maintained.

Distance from turbines affects other variables, but alone its influence is unclear. The “proximity hypothesis” has yielded confounding findings in the literature. What is known is that an individual’s distance from existing turbines affects a number of other correlates, including visual, sound, and socioeconomic impacts.

Other variables also affect acceptance, and the understanding of these is evolving. Researchers have proposed a wide range of other variables potentially correlated to wind energy acceptance, many of which deserve further study. Over time the addition of more possible correlates adds to the depth of understanding in this field.

7. Knowledge gaps after 30 years: Areas for future research

A number of questions remain unresolved after three decades of research in this field. The following are specific areas for future research.

A widespread, representative, random survey should be conducted in North America. Previous studies on acceptance of wind energy in North America have focused on only one or a few wind facilities. A more geographically representative survey examining the variables discussed in this paper would greatly advance the state of knowledge in this field.

Individuals living closest to turbines should be oversampled. The detailed experiences and attitudes of those living closest to turbines (i.e., within half a mile) have not been well captured. Future research should oversample this group and analyze their responses as a group that is distinct from those living further away.

Comparability of case studies should be enhanced. Discrete case studies should utilize some standardized survey items and protocols to facilitate comparison with data collected at different sites by other researchers.

Causation should be identified, where possible. Many studies have used regression techniques to tease out competing correlates of acceptance, but in many cases the *direction* of influence (i.e., causality) of these correlates is not understood.

Wind energy acceptance should be compared with acceptance of other energy sources. Only a few North American studies have examined wind acceptance in concert with acceptance of other energy sources (e.g. Jacquet, 2012). Future research should attempt to do so to provide a mechanism for comparison.

Change in acceptance over time should be studied. Longitudinal studies of acceptance over time (i.e., before, during, and after wind project construction) have revealed interesting changes in the European literature (e.g. Wolsink, 2007), but they have rarely been conducted in North America—a notable exception being Firestone et al. (2012a), but that study only covered the development and planning periods, leaving construction and post-construction periods in question. Similarly, the attitudes among respondents who moved into an area *after* the wind facility began operation have not been studied in depth.

Annoyance survey data should be combined with measured or modeled sound-level data. A number of surveys have asked respondents about their level of annoyance and perceived health impacts from wind turbine sound, but very few (e.g. Magari et al., 2014) have correlated those data to measured or modeled sound-level data.

Varying development-process models and experiences should be studied. Participation in, perceptions of, and resident preferences for the wind facility development process are not well understood.

Compensation mechanisms should be compared more rigorously. More research is needed to understand appropriate and acceptable compensation mechanisms for individuals and communities, such as local ownership and investment opportunities, community compensation schemes, and non-monetary community benefits.

Resident perceptions of property-value impacts should be studied in greater depth. Although recent large-scale research has not found a significant property-value impact on homes near wind facilities, those impacts may exist in some cases, and the *perception* of value impacts among local residents could exist, but is not well understood.

Implementation of research recommendations should be studied. Research is needed to understand the effects and implementation of strategies proposed in the literature during the development and policy-making process. Researchers should continue to develop frameworks for wind project planning that increases community engagement and reduces conflict and injustice.

8. Conclusion

The efforts of wind energy acceptance researchers over the past 30 years have yielded many important lessons and insights, but much work remains to be done in this space—particularly in the North American context. Thirty years from today, wind energy could conceivably generate over 30% of North America's electricity, representing a significant increase over the current installed capacity. More turbines will result in more nearby "neighbors," increasing the population that experiences the direct impacts of wind energy. Opposition and negative attitudes will, undoubtedly, still exist. However, with continued research and a commitment to implement research findings into developer and policymaker practice, conflict and perceived injustices might be significantly reduced.

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Appendix A

Table 1: Explanatory variables in N.A. wind acceptance literature & research suggestions

Explanatory Variable	Sub-variable	North American Citations	Further Research
Socio-economic aspects	Landowner compensation	*Baxter et al., 2013* *Firestone et al., 2012b* *Garcia et al., 2016* *Gipe, 1995* *Groth & Vogt, 2014* *Jacquet, 2012* *Walker et al., 2014b*	What do hosting and non-hosting neighbors perceive to be the most appropriate forms of compensation? What forms of community-level compensation are preferred?
	Community investment & ownership models	*Bolinger, 2005* *Brannstrom et al., 2011* *Fast et al., 2016* *Ferguson-Martin & Hill, 2012* *Songsore & Buzzelli, 2015* *Sovacool & Ratan, 2012*	More research is needed on this topic in the North American context. How to enable community investment in private developer-led wind projects?
	Property value impacts	*Abbott, 2010* *Fast et al., 2015* *Firestone & Kempton, 2007* *Heintzelman & Tuttle, 2012* *Hoen et al., 2011; 2015* *Hoen & Atkinson-Palombo, 2016* *Walker et al., 2014a*	What source of information is trusted for property value impacts? Are there community compensation mechanisms that could assuage concerns about property value impacts?
	Tourism impacts	*Firestone et al., 2009* *Landry et al., 2012* *Lilley et al., 2010* *Lutzeyer, 2013*	Are there methods to enhance tourism near wind projects? Does this impact differ between onshore and offshore projects?
	Impacts on electricity rates	*Baxter et al., 2013* *Firestone & Kemption, 2007* *Firestone et al., 2012a* *Petrova, 2016*	
	Jobs and local economic development	*Bidwell, 2013* *Larson & Krannich, 2016* *Mulvaney et al., 2013a; 2013b* *Olson-Hazboun et al., 2016* *Slattery et al., 2012* *Songsore & Buzzelli, 2015*	How are local economic impacts perceived under more participatory development processes?
	Distributive justice / costs and benefits	*Baxter et al., 2013* *Brannstrom et al., 2011* *Groth & Vogt, 2014* *Huesca-Pérez et al., 2016* *Hirsh & Sovacool, 2013* *Jami & Walsh, 2017* *Kempton et al., 2005* *Larson & Krannich, 2016* *Pasqualetti, 2011a* *Petrova, 2013; 2016* *Phadke, 2011; 2013* *Rule, 2014* *Shaw et al., 2015* *Slattery et al., 2012* *Sovacool, 2009*	What do developers and communities perceive as best practices for distributive justice? What are the preferred community compensation mechanisms to improve distributive justice? How are feelings of distributive justice influenced by participation in the planning process? How to enable community investment in private developer-led wind projects?

Sound Aspects	Health impacts	*Baxter et al., 2013* *Knopper & Ollson, 2011* *Knopper et al., 2014* *Magari et al., 2014* *Michaud et al., 2016a; 2016b* *Songsore & Buzzelli, 2014* *Walker et al., 2014c*	What types of sounds cause the most stress or sleep disruption?
	Annoyance	*Kaliski & Neeraj, 2013* *Knopper & Ollson, 2011* *Knopper et al., 2014* *Nissenbaum et al., 2012* *Petrova, 2016* *Phadke, 2013*	What types of sounds are most annoying? Is measured or modeled sound correlated to levels of annoyance? If not, how can the sound models be improved?
Visual & Landscape Aspects	Aesthetic aspects, beauty, & annoyance	*Apostol et al., 2016* *Brannstrom et al., 2011* *Bush & Hoagland, 2016* *Fast et al., 2015* *Fergen & Jacquet, 2016* *Firestone & Kemption, 2007* *Firestone et al., 2015* *Gipe, 1993; 1995* *Hirsch & Sovacool, 2013* *Jacquet & Stedman, 2013* *Krueger et al., 2011* *Larson & Krannich, 2016* *Olson-Hazboun et al., 2016* *Pasqualetti, 2000; 2001; 2011a* *Pasqualetti & Bultler, 1987* *Pasqualetti et al., 2002* *Petrova 2016* *Phadke, 2010* *Rule, 2014* *Thayer & Freeman, 1987*	What are the motivations for positive visual perceptions? Does physical geography influence attitudes or visual annoyance? Does the number of turbines or frequency of seeing turbines influence attitudes? How do visual simulations influence support/opposition? How can simulations, and how they are presented, be improved to better reflect actual developments?
	Economic effects of visual impacts (e.g. willingness to accept view)	*Boatwright, 2013* *Groothuis et al., 2008* *Jensen et al., 2014* *Krueger et al., 2011* *Pasqualetti, 2001*	
	Place Attachment	*Bidwell, 2013* *Fast & Mabee, 2015* *Firestone et al., 2009* *Jacquet & Stedman, 2013*	More research on place attachment is needed in the North American context.
Environmental concerns and attitudes	Environmental attitudes and perceived impacts	*Abbott, 2010* *Fergen & Jacquet, 2016* *Firestone et al., 2009; 2012a* *Firestone & Kempton, 2007* *Kempton et al., 2005* *Larson & Krannich, 2016* *Mulvaney et al., 2013a; 2013b* *Olson-Hazboun et al., 2016* *Petrova, 2016* *Thayer & Freeman, 1987*	How do environmental concerns and motivations vary in different socio-policicital contexts?

	Climate change	*Bidwell, 2015* *Olson-Hazboun et al., 2016* *Petrova, 2013; 2016* *Slattery et al., 2012* *Swofford & Slattery, 2010*	Do residents believe the local wind project makes a difference with respect to climate change?
Planning process, fairness, trust	Community participation in development process	*Bidwell, 2016b* *Bohn & Lant, 2009* *Corscadden et al., 2012* *Fast et al., 2016* *Firestone et al., 2012b* *Groth & Vogt, 2014* *Huesca-Pérez et al., 2016* *Jacquet, 2015* *Jami & Walsh, 2014; 2017* *Phadke, 2011; 2013* *Shaw et al., 2015* *Songsore & Buzzelli, 2015* *Sovacool & Ratan, 2012* *Walker et al., 2014c*	How should developers implement a more participatory, collaboartive planning process? What communication practices and techniques are most effective between stakeholders? What do project developers consider best practices?
	Fairness, trust, and relationships	*Dwyer, 2016* *Fast, 2015* *Fast & Mabee, 2015* *Fast et al., 2016* *Firestone et al., 2012b* *Shaw et al., 2015* *Songsore & Buzzelli, 2014*	Do perceptions of fairness influence perceptions of economic impacts or reported health impacts?
Distance from turbines	Proximity hypothesis	*Baxter et al., 2013* *Groth & Vogt, 2014* *Swofford & Slattery, 2010* *Thayer & Freeman, 1987*	Do residents move in and out over time based on attitudes (Tiebout sorting)? Do individuals living closest to turbines have distinct attitudes or impacts?
	Cumulative impacts	*Olson-Hazboun et al., 2016* *Petrova, 2013* *Walker et al., 2014c*	The influence of cumulative impacts on communities needs further study in North America
Other	Knowledge / information deficit	*Baxter et al., 2013* *Bidwell, 2016a* *Bosley & Bosley, 1988* *Bush & Hoagland, 2016* *Corscadden et al., 2012* *Fast, 2015* *Klick & Smith, 2010* *Sovacool, 2009* *Swofford & Slattery, 2010*	What kinds of entities are trusted sources for information about wind energy? What are preferred methods for presenting information? How can a bi-lateral exchange of information between the hosts and developers be encouraged?
	Influence of local or federal policy on local acceptance	*Fast & Mabee, 2015* *Petrova, 2014* *Songsore & Buzzelli, 2014; 2015*	Compare policies that have increased acceptance to those that have decreased it
	Compare attitudes toward wind with other energy sources	*Jacquet, 2012* *Jacquet & Stedman, 2013* *Shaw et al., 2015*	More comparisons of preferences/attitudes toward different energy sources are needed.

Table 2: Research approaches and methods in North American wind acceptance literature

Research Approach	Specific Method	North American Citations
Quantitative Methods	One-time case study, statistical survey near existing wind facility	*Baxter et al., 2013* *Fergen & Jacquet, 2016* *Firestone et al., 2015* *Groth & Vogt, 2014* *Jacquet, 2012; 2015* *Jacquet & Stedman, 2013* *Magari et al., 2014* *Mulvaney et al., 2013* *Nissenbaum et al., 2012* *Olson-Hazboun et al., 2016* *Paller, 2014* *Pasqualetti & Butler, 1987* *Petrova, 2014; 2016* *Slattery et al., 2012* *Swofford & Slattery, 2010* *Thayer & Freeman, 1987*
	One-time case study, statistical survey; hypothetical wind facility	*Bidwell, 2013; 2015; 2016a* *Boatwright, 2013* *Corscadden et al., 2012* *Firestone & Kempton, 2007* *Firestone et al., 2009; 2012b* *Groothuis et al., 2008* *Landry et al., 2012* *Larson & Krannich, 2016* *Lutzeyer, 2013*
	Longitudinal case study survey (over time)	*Firestone et al., 2012a*
	Nationally representative opinion poll	*Ipsos, 2010* *Klick & Smith, 2009* *Leiserowitz et al., 2014* *Vyas & Hurst, 2013*
	Economic modeling and choice experiments	*Garcia et al., 2016* *Groothuis et al., 2008* *Heintzelman & Tuttle, 2012* *Hoen et al., 2011; 2015* *Hoen & Atkinson-Palombo, 2016* *Kreuger et al., 2011* *Landry et al., 2012* *Lang et al., 2014* *Lilley et al., 2010* *Lutzeyer, 2013*
	Epidemiological studies	*Michaud et al., 2016a; 2016b* *Nissenbaum et al., 2012*
Mixed Methods	Interview and Survey	*Bosley & Bosley, 1988* *Kreuger et al., 2011* *Mulvaney, 2013a; 2013b* *Walker et al., 2014a; 2014b; 2014c*
	Interview and Content Analysis / Literature Review	*Fast et al., 2015* *Sovacool & Ratan, 2012*
	Q-method	*Brannstrom et al., 2011*

Qualitative Methods	Literature review	*Fast, 2015* *Fournis & Fortin, 2016* *Huesca-Pérez et al., 2016* *Knopper & Ollson, 2011* *Knopper et al., 2014* *Lantz & Flowers, 2011* *Pasqualetti, 2011b* *Petrova, 2013* *Rule, 2014*
	Content analysis	*Abbott, 2010* *Bohn & Lant, 2009* *Bolinger, 2005* *Ferguson-Martin & Hill, 2012* *Pasqualetti, 2011a* *Phadke, 2010* *Shaw et al., 2015* *Songsore & Buzzelli, 2014; 2015*
	Interview / Focus Group	*Dwyer, 2016* *Fast & Mabee, 2015* *Jami & Walsh, 2017* *Kempton et al., 2005* *Pasqualetti, 2001* *Phadke, 2013* *Shaw et al., 2015* *Sovacool, 2009*
	Comment / Perspective / Qualitative case study	*Bidwell, 2016b* *Fast et al., 2016* *Hirsch & Sovacool, 2013* *Jami & Walsh, 2014* *Pasqualetti, 2000* *Phadke, 2011*
	Expert elicitation	*Bush & Hoagland, 2016*

Review of Studies and Literature Relating to Wind Turbines and Human Health

Prepared by Public Service Commission Staff for the Wisconsin State Legislature in Response to 2015 Wisconsin Act 55

December 2015

Introduction

The Public Service Commission of Wisconsin (Commission) was directed by 2015 Wisconsin Act 55 (Act 55) to "conduct a review of studies conducted to ascertain the health effects of industrial wind turbines on persons residing near the turbine installations." This requirement is similar to the work recently done by the Wind Siting Council[1] (WSC) in an earlier report to the Legislature (2014 WSC report).

Wisconsin Stat. § 196.378(4g)(e) directs the WSC to "survey the peer-reviewed scientific research regarding the health impacts of wind energy systems and study state and national regulatory developments regarding the siting of wind energy systems." This section also requires the production of a report for the Wisconsin State Legislature every five years, putting a recurring obligation upon the members of the WSC to review current scientific literature on the topic of health impacts of wind energy systems and regulatory trends. The WSC's 2014 report, the first such required report, was delivered to the Wisconsin State Legislature at the end of October 2014. Commission staff was closely involved with identifying source materials and assisting with the writing of this document. The WSC is tasked with producing another such report by October 2019. This task also requires that the WSC determine whether recommendations on any legislation should be suggested, based on information in the research or regulatory developments.

Commission staff recognizes the work done by the WSC and has not used sources that were evaluated and either used or dismissed by the WSC's work during the production of the 2014 WSC report. Rather, Commission staff has sought any directly relevant studies or literature that were made available from the time when the WSC stopped taking in new literature, August 2013, until October 2015, when Commission staff began the task of summarizing findings and writing this current document. The 2014 WSC report, which included two minority reports, was the product of almost two years of research, discussion, and writing. This process will likely begin again in late 2017.

Based on the few additional studies in the current review, the research literature on this subject continues to show trends similar to those identified in the 2014 WSC report. There is an association between exposure to wind turbine noise (WTN) and annoyance for some residents near wind energy systems. Some researchers show this as a causal relationship. There is more limited and conflicting evidence that shows association or a causal relationship between wind turbines and sleep disturbance. There is a lack of evidence to support other hypotheses regarding human health effects caused by wind energy systems.

Commission staff identified a number of documents that address the topic of "human health effects of wind energy systems" from a number of sources. As indicated above, Commission staff did not revisit documents that were included in the 2014 WSC report, or more recently published review articles by authors of documents included in the 2014 WSC report where the study methods and results were the same and there was no significant new analysis done. The goal

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[1] A Wind Siting Council of Public Service Commission-appointed members was established in the Public Service Commission by Wis. Stat. § 15.797.

was to identify any new direct research or new analysis that might provide additional insight into this topic. Articles that did not directly examine health effects, but rather explored hypotheses that could lead to health effects or discussed ways to model or measure sound produced by turbines were not included. A link to the 2014 WSC report is attached as an appendix to this report to provide the reader with the previous review and analysis done on this subject.

Health Canada Study

Health Canada is the Canadian federal agency responsible for national public health. In response to public concern regarding potential health impacts from wind turbines, Health Canada, in partnership with Statistics Canada, undertook a $2.1 million Canadian Dollar epidemiological study to evaluate the health of people living up to 10 kilometers (km) (6.2 miles) from wind turbine installations. The study took place in communities in southern Ontario and Prince Edward Island. Preliminary results were published in November 2014, and the study's authors state that these are considered preliminary until published in the peer-reviewed scientific literature.[2] Only results published in the peer-reviewed literature are provided in this report. It is anticipated that more results will be made available in the peer-reviewed literature by the time of the next WSC report.

The Health Canada study went through a lengthy and open development process prior to the study taking place. A panel of experts that included epidemiologists, acoustic engineers, academics, neurologists, statisticians, and wind energy engineers developed the study design. The members of the expert panel were screened for activities or affiliations that would present bias or conflict with their mandate, and were required to sign confidentiality statements. The study methods and details of the research design committee were put out for a 60-day comment period.[3] After the comment period ended, Health Canada provided a summary of the comments received, along with responses from the research committee. This openness allowed for a clear showing of the methods and reasons for the study design, where evaluations and changes were made after comments, and how certain comments were understood but why no changes were made. The study design was also evaluated by the Health Canada Science Advisory Board and the World Health Organization Noise Committee.

Health Canada Study Methods

The study consisted of three main parts:

1. An in-person questionnaire, given to randomly selected adult participants living at various distances from the wind turbines. The study found 1,570 eligible households in the study areas, of which 1,238 households participated (78.9 percent).

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[2] Such publications are starting to be seen at the time of this report. Feder *et al*. 2015, later in this section, describes the quality of life analysis. An article was also published in SLEEP, October 2015 (abstract with results reviewed, full text not yet available), describing specifically the results of the sleep and wind turbine noise (WTN) exposure part of the study.

[3] The specific planned locations and timing of the survey were not made available to prevent bias.

2. A collection of physical health measures that assessed stress levels using hair cortisol, blood pressure, sleep actimetry[4] (over seven days) and resting heart rate. This goal of obtaining objective measures of health sets the Health Canada study apart from many other studies on this subject, which rely only on self-reported health effects.

3. More than 4,000 hours of WTN measurements were conducted to support the modeled calculations of WTN levels at homes in the study.

The study aimed to test all households located within 600 meters of a wind turbine in the study area, with others between 600 meters and 10 km randomly selected. One randomly selected adult in each household was selected to participate in the study. Details of house construction, including the dimensions of the participants' bedrooms were obtained during the survey to assist with sound level modeling.

Although the Health Canada study represents one of the larger and more comprehensive studies regarding health effects of wind turbines, it does not allow for making causal inferences. It does allow conclusions to be made with respect to associations between endpoints. As stated in the preliminary findings:

> *The current cross-sectional study is an observation study at one point in time among a sample of subjects living various distances from wind turbines. The temporality of the relationship renders it difficult to establish if exposure to wind turbine sound precedes the investigated health endpoints or if the health endpoints are already present before being exposed. Therefore this design does not permit any conclusions to be made with respect to causality.*

Health Canada clearly includes a disclaimer that the results produced by the study do not provide definitive answers on their own and should be considered in conjunction with other research available on the topic.

Health Canada Study Results

Calculated outdoor A-weighted WTN levels for the homes participating in the study reached 46 A-weighted decibels (dBA) for wind speeds of 8 meters/second. Use of A-weighted scales in evaluating noise is a common method of measuring environmental noise and assessing potential noise health effects. It is meant to represent the noise filtering process of the human ear, putting less importance on frequencies to which human ears are less sensitive. Other ways of assessing noise could use different weighted scales, and some argue that using A-weighted scales underrepresents low frequency sounds. The Health Canada study also calculated C-weighted sound levels to attempt to better assess the low frequency levels, but found A and C weighted levels were so close as to provide the same information.[5] The calculated WTN levels are likely to be representative of yearly averages with an uncertainty of about ±5 dB.

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[4] Small watch-like devices were worn by participants to provide an objective measurement of sleep over a 7-day period.

[5] Feder *et al*. 2015

An article[6] published by the panel of the study described in greater detail the World Health Organization Quality of Life[7] questionnaire (WHOQOL-BREF) used in the Health Canada study, as well as the results seen using univariate analyses and multiple linear regression models. It found that lower scores (less indication of satisfaction with quality of life) on the physical and environment domains of the questionnaire were observed among participants that reported high visual annoyance towards wind turbines. Higher scores (more indication of satisfaction with quality of life) on the physical domain of the questionnaire were seen in participants that received a personal benefit from wind turbines (such as rental payments). Overall, the analysis of the study results do not support an association between exposure to WTN up to 46 dBA (modeled) and quality of life assessed. The article does agree with some other researchers that some quantification of amplitude modulation[8] and tonality produced from WTN would provide further information into how WTN may influence quality of life. The Health Canada study results do not support an association between exposure to WTN up to 46 dBA and sleep disruption as measured through actimetry.[9]

Additional Published Empirical Research

In addition to the large study conducted by Health Canada, Commission staff identified two additional cross-sectional studies that were published after the cutoff date for those evaluated in the 2014 WSC report. Brief summaries of their methods and results are provided below. Both of these have been incorporated into the critical reviews done by other organizations as described later in this document.

New York (Magari *et al*. 2014)

This was a study in western New York State, where a 126 megawatt wind energy system consisting of 84 turbines covered an area of 19 square miles. Fifty-six homes in the area were randomly selected (out of 256 possible), and the researchers were able to conduct surveys at 52 of these. Sixty-two individuals were interviewed with a survey that was adapted from that previously used by researchers in the Netherlands.[10] This study also collected short-term sound measurements inside and outside of respondents' homes. Average wind speeds that were below the wind speeds typically present in the wind energy system and the short-term nature of the measurements makes comparisons with other studies' findings that use modeled sound levels difficult. Supplementing these short-term measurements with modeled sound levels would improve the ability of the study to compare self-reported health and quality of life data with

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[6] Feder *et al*. 2015.

[7] The World Health Organization defines Quality of Life (QOL) as a broad multidimensional concept that includes subjective evaluations of both positive and negative aspects of life. Physical domains of health are joined with social, psychological, and environmental domains to create a complex series of measurements. Evaluated items are ranked from a low of 1 to a high of 5.

[8] Amplitude modulation is used in this context to refer to increased variation of sound levels produced by the aerodynamic noise of the blades of the turbines as they pass the tower. Several articles explore how this effect can occur, how levels could be "enhanced" and how it could be incorporated into noise modeling for projects. See Larsson and Öhlund (2013), and Kaliski (2014) as two examples of this topic of discussion.

[9] Michaud *et al.* 2015.

[10] Pedersen and Waye (2007), reviewed in the 2014 WSC report.

average sound levels at each residence. The survey results did not support an exposure-response relationship between short-term indoor or outdoor noise exposure and self-reported annoyance.

Looking instead at the survey responses, they found that there was a correlation between an individual's concern regarding health effects and the prevalence of sleep disturbance or stress among the study population. Ninety percent of the survey participants stated they were either very satisfied or satisfied with their living environment. Thirty-four percent had a negative or very negative view of wind turbines, while 44 percent had a positive or very positive opinion of turbines. The subjective sound descriptor of "swishing" when describing WTN was significantly negatively correlated with an individual's level of satisfaction with their living environment. This study did not include the type of sound monitoring that would be needed to characterize amplitude modulation, which is commonly seen as one cause of this sound characteristic in relation to WTN.

The study found that general annoyance from WTN was statistically correlated with an individual's: (1) general opinion on wind turbines; (2) opinions on altered landscapes; (3) concern over health effects associated with wind turbines; and (4) their sensitivity to noise in general. There was a statistically significant association between an individual's satisfaction with their living environment and if they had some type of relationship with the energy company, such as rental agreements.

Poland (Pawlaczyk-Luszczynska *et al*. 2014)

This study analyzed the relationships between distance and levels of WTN at residences and the percentage of people annoyed by the noise, as well as the individual factors affecting the perceived annoyance. Questionnaires were given to 361 subjects living in the vicinity of 8 wind energy systems in central and northwest Poland. Sound levels were modeled following the sound propagation model used by previous studies such as Pederson and Waye (2004). Noise levels were measured outside some of the respondents' houses to verify the calculated sound levels.

Preliminary analyses of this study found exposure-response relationships between A-weighted sound levels and annoyance. Where sound levels were calculated at 31-50 dBA, almost one-third of participants found outdoor WTN annoying. Although the study found there were no significant difference in subjects noticing WTN compared to other sources of environmental noise, where WTN was noticed, it was more frequently assessed as annoying compared to other environmental noise. Strong correlations were observed between subjective factors such as attitude to wind turbines in general and their visual impact on landscape and levels of annoyance. Generally, the results of this study are similar to those in earlier Swedish and Dutch cross-sectional studies reviewed in the 2014 WSC report.

Additional Literature Reviews

There were four new reviews found published in peer-reviewed journals in the time period of this report. The same caveats as were expressed in the 2014 WSC report[11] apply with regard to the quantity and quality of the research available for such review articles to consider. Three of these

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[11] At pp. 7-8.

review articles[12] restricted the reviews to peer-reviewed scientific literature, while the fourth[13] imposed no such restriction on the quality of the literature, but specified the topic suitable and identified bias where it was likely to exist.

McCunney *et al*. 2014

The Canadian Wind Energy Association (CanWEA) funded a critical review of peer-reviewed literature regarding evaluations of potential health effects among people living in the vicinity of wind turbines by academic staff at the Massachusetts Institute of Technology (MIT). The coauthors of the paper have backgrounds in occupational and environmental medicine, acoustics, epidemiology, otolaryngology, psychology and public health.[14] This review assessed many of the same studies reviewed by the WSC in its 2014 report. Some additional papers were reviewed that had not been published by the time of the 2014 WSC report literature deadline.[15]

The review found four results:

1. Infrasound near wind turbines does not exceed audibility thresholds;

2. Epidemiological studies have shown associations between living near wind turbines and annoyance;

3. Infrasound and low-frequency sound do not present unique health risks; and

4. Annoyance seems more strongly related to individual characteristics than noise from turbines.

Onakpoya *et al*. 2014

This was a review and analysis of the eight studies[16] that met their selection criteria, which the authors describe as “moderate” in quality. The authors are academic researchers with no stated interests with regards to wind energy systems. The results show that living in areas with wind energy systems appears to result in annoyance and may be associated with sleep disturbances and decreased quality of life. The review suggests that visual perception of turbines is correlated with increased episodes of annoyance and that reported adverse effects are more prominent in quiet areas compared with noisy ones. Individual attitudes could influence the type of response to noise from wind turbines. The review does state that as the response variables measured in the studies are subjective, causality between the variables cannot be established.

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[12] McCunney *et al*. 2014; Onakpoya *et al*. 2014; and Knopper *et al*. 2014.

[13] Schmidt and Klokker. 2014.

[14] A statement accompanying the article reads: “Although the funding for this project came from CanWEA through a grant to the Department of Biological Engineering of MIT, members of CanWEA did not take part in editorial decisions or reviews of the manuscript. MIT conducted an independent review of the final manuscript to ensure academic independence of the commentary and eliminate any bias in the interpretation of the literature.”

[15] Both McCunney *et al*. 2014 and Onakpoya *et al*. 2014 review Magari *et al*. 2014 and Pawlaczyk-Luszczyriska *et al*. 2014, which are research studies published after the 2014 WSC report was being written.

[16] Six of these had been included in those articles reviewed by the WSC for its 2014 report.

Schmidt and Klokker (2014)

The authors are clinical researchers with no stated interests with regards to wind energy systems. They conducted a systematic review of literature from both peer-reviewed and non-peer-reviewed internet sources.[17] To be included, studies must have investigated any relationship between WTN exposure and health-effect outcomes. No limiting criteria regarding the quality of the research was used in the initial selection process, but risk of bias identified in any of the studies was assessed after review and reported as part of a quality assessment of the studies.

This review clearly states that while case series studies (four of which were reviewed) can generate hypotheses, due to the general likelihood of bias, they contribute weak evidence towards evidence of causation. The rest of the 26 publications were cross-sectional studies. Selection bias[18] and observational bias[19] are still recognized as likely to occur within these studies, and therefore, they also cannot be used to determine specific causal relationships. Even with the more relaxed criteria for literature, the review found similar results to other articles.

> *This review found that evidence of a dose-response relationship between wind turbine noise linked to noise annoyance, sleep disturbance and possibly psychological distress[20] was evident in the studies reviewed. Currently there is no further existing statistically-significant evidence indicating any association between wind turbine noise exposure and tinnitus, hearing loss, vertigo or headache.*

The authors suggest that future studies should focus on investigations aimed at objectively demonstrating whether measurable health-related outcomes can be proven to fluctuate depending on exposure to wind turbines.

Knopper *et al*. 2014

This revisited a previous review[21] of the literature relating to wind turbines and health effects, looking specifically for new evidence in the studies that had been published since the previous review. The authors are made up of environmental health scientists that do work with wind power companies. For their updated review, they searched the literature and restricted their review to peer-reviewed articles, but did not restrict their review to articles or studies of direct evidence.

This review is bibliographic in nature and provides brief summaries of the articles reviewed, under topic headlines such as “low-frequency noise and infrasound.” Many of these articles were also reviewed in the 2014 WSC report. They find that there is a lack of evidence that suggests that

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[17] Referenced specifically in this study was that three websites highly critical of wind energy systems were checked for articles that did not come up in Google Scholar or other searches and suitable literature reviewed.

[18] Selection bias occurs where proper randomization of subjects is not achieved either through selecting specific subjects or allowing subjects to self-select. This can lead to the distortion of statistical analysis and inaccuracies.

[19] Observational bias, also known as information bias, can occur in several ways and are errors in measurement or misclassifications that can affect results. Self-recall of symptoms or effects are a common source of such bias.

[20] Sleep disturbance and psychological distress were only reported in self-reported questionnaires which increase the risk of introducing information bias into the study.

[21] Knopper and Ollson, 2011 (reviewed in the 2014 WSC report).

factors such as electromagnetic fields, shadow flicker, low-frequency noise and infrasound affect human health. They find annoyance may be associated with WTN, and that this annoyance may be associated with self-reported health effects, particularly where exposure to sound levels by non-participants is regularly greater than 40 dBA. They recommend incorporating sound measurements into setback distances and conducting post construction monitoring to ensure modeled sound levels are within limits. This review also discusses the influence psychogenic or subjective factors have on annoyance and other health complaints and identifies these as potentially resulting in levels of annoyance even when noise exposures are below sound level limits.

Conclusion

Concern over whether wind energy systems impact human health continues to prompt new research. For the purposes of this report, Commission staff restricted the acceptance of literature to new peer-reviewed direct studies or critical reviews of such literature published in peer-reviewed journals. There are numerous articles and papers that explore the hypotheses relating to infrasound, low frequency noise, amplitude modulation, and how WTN should be measured or modeled.[22] Other articles explore the hypotheses regarding whether some of the impacts associated with wind turbines could be explained through psychogenic factors[23] or effects to the vestibular system.[24] These may prove useful for future research on health effects or experts working on sound measurement protocols.

Commission staff regularly searches for new articles and research done on this subject and reviews materials for new information. With more analysis of the results of the Health Canada study expected, as well as potentially new research from Australia and Denmark, it is likely that the WSC will have new studies and reviews to use in its next report to the Legislature. The WSC may choose to review sources cited within this document as part of the already scheduled analysis of literature relating to the health impacts of wind turbines leading up to the October 2019 WSC report. Commission staff does not intend for the current report to be the only consideration of the documents reviewed if WSC members also choose to review the documents as part of their statutorily required report.

Presently, the recent literature on this subject continues to reach conclusions similar to those identified in the 2014 WSC report. The studies have found an association between exposure to wind turbine noise and annoyance for some residents near wind energy systems. Some studies show this as a causal relationship between wind turbines and annoyance. There is more limited and conflicting evidence demonstrating an association or a causal relationship between wind turbines and sleep disturbance. There is a lack of evidence to support other hypotheses regarding human health effects caused by wind energy systems. Overall, the research in this area is limited and insufficient to determine causal relationships between variables.

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[22] Berger *et al*. 2015; Maffei *et al*. 2015.

[23] Crichton *et al*. 2014.

[24] Harrison 2014; Salt and Lichtenhan 2014.

Acronyms

§	Section
CanWEA	Canadian Wind Energy Association
dB	Decibel
dBA	A-weighted decibel
Commission	Public Service Commission of Wisconsin
km	Kilometers
MIT	Massachusetts Institute of Technology
QOL	Quality of life
WHOQOL-BREF	World Health Organization Quality of Life questionnaire
Wis. Stat.	Wisconsin Statute
WSC	Wind Siting Council
WTN	Wind turbine noise

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Appendix A

A copy of the 2014 WSC report to the Wisconsin Legislature can be found on the Public Service Commission website at: http://psc.wi.gov/renewables/documents/windSitingReport2014.pdf.

It includes both minority reports as well as appendices.

Wind Turbine Health Impact Study:

Report of Independent Expert Panel

January 2012

Prepared for:

Massachusetts Department of Environmental Protection

Massachusetts Department of Public Health

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The Panel Charge

The Expert Panel was given the following charge by the Massachusetts Department of Environmental Protection (MassDEP) and Massachusetts Department of Public Health (MDPH):

1. Identify and characterize attributes of concern (e.g., noise, infrasound, vibration, and light flicker) and identify any scientifically documented or potential connection between health impacts associated with wind energy turbines located on land or coastal tidelands that can impact land-based human receptors.
2. Evaluate and discuss information from peer-reviewed scientific studies, other reports, popular media, and public comments received by the MassDEP and/or in response to the *Environmental Monitor Notice* and/or by the MDPH on the nature and type of health complaints commonly reported by individuals who reside near existing wind farms.
3. Assess the magnitude and frequency of any potential impacts and risks to human health associated with the design and operation of wind energy turbines based on existing data.
4. For the attributes of concern, identify documented best practices that could reduce potential human health impacts. Include examples of such best practices (design, operation, maintenance, and management from published articles). The best practices could be used to inform public policy decisions by state, local, or regional governments concerning the siting of turbines.
5. Issue a report within 3 months of the evaluation, summarizing its findings.

To meet its charge, the Panel conducted a literature review and met as a group a total of three times. In addition, calls were also held with Panel members to further clarify points of discussion.

Executive Summary

The Massachusetts Department of Environmental Protection (MassDEP) in collaboration with the Massachusetts Department of Public Health (MDPH) convened a panel of independent experts to identify any documented or potential health impacts of risks that may be associated with exposure to wind turbines, and, specifically, to facilitate discussion of wind turbines and public health based on scientific findings.

While the Commonwealth of Massachusetts has goals for increasing the use of wind energy from the current 40 MW to 2000 MW by the year 2020, MassDEP recognizes there are questions and concerns arising from harnessing wind energy. The scope of the Panel's effort was focused on health impacts of wind turbines *per se*. The panel was *not* charged with considering any possible benefits of avoiding adverse effects of other energy sources such as coal, oil, and natural gas as a result of switching to energy from wind turbines.

Currently, "regulation" of wind turbines is done at the local level through local boards of health and zoning boards. Some members of the public have raised concerns that wind turbines may have health impacts related to noise, infrasound, vibrations, or shadow flickering generated by the turbines. The goal of the Panel's evaluation and report is to provide a review of the science that explores these concerns and provides useful information to MassDEP and MDPH and to local agencies that are often asked to respond to such concerns. The Panel consists of seven individuals with backgrounds in public health, epidemiology, toxicology, neurology and sleep medicine, neuroscience, and mechanical engineering. All of the Panel members are considered independent experts from academic institutions.

In conducting their evaluation, the Panel conducted an extensive literature review of the scientific literature as well as other reports, popular media, and the public comments received by the MassDEP.

ES 1. Panel Charge

1. Identify and characterize attributes of concern (e.g., noise, infrasound, vibration, and light flicker) and identify any scientifically documented or potential connection between health impacts associated with wind turbines located on land or coastal tidelands that can impact land-based human receptors.
2. Evaluate and discuss information from peer reviewed scientific studies, other reports, popular media, and public comments received by the MassDEP and/or in response to the *Environmental Monitor Notice* and/or by the MDPH on the nature and type of health complaints commonly reported by individuals who reside near existing wind farms.
3. Assess the magnitude and frequency of any potential impacts and risks to human health associated with the design and operation of wind energy turbines based on existing data.
4. For the attributes of concern, identify documented best practices that could reduce potential human health impacts. Include examples of such best practices (design, operation, maintenance, and management from published articles). The best practices could be used to inform public policy decisions by state, local, or regional governments concerning the siting of turbines.
5. Issue a report within 3 months of the evaluation, summarizing its findings.

ES 2. Process

To meet its charge, the Panel conducted an extensive literature review and met as a group a total of three times. In addition, calls were also held with Panel members to further clarify points of discussion. An independent facilitator supported the Panel’s deliberations. Each Panel member provided written text based on the literature reviews and analyses. Draft versions of the report were reviewed by each Panel member and the Panel reached consensus for the final text and its findings.

ES 3. Report Introduction and Description

Many countries have turned to wind power as a clean energy source because it relies on the wind, which is indefinitely renewable; it is generated “locally,” thereby providing a measure of energy independence; and it produces no carbon dioxide emissions when operating. There is interest in pursuing wind energy both on-land and offshore. For this report, however, the focus is on land-based installations and all comments are focused on this technology. Land-based wind turbines currently range from 100 kW to 3 MW (3000 kW). In Massachusetts, the largest turbine is currently 1.8 MW.

The development of modern wind turbines has been an evolutionary design process, applying optimization at many levels. An overview of the characteristics of wind turbines, noise, and vibration is presented in Chapter 2 of the report. Acoustic and seismic measurements of noise and vibration from wind turbines provide a context for comparing measurements from epidemiological studies and for claims purported to be due to emissions from wind turbines. Appendices provide detailed descriptions and equations that allow a more in-depth understanding of wind energy, the structure of the turbines, wind turbine aerodynamics, installation, energy production, shadow flicker, ice throws, wind turbine noise, noise propagation, infrasound, and stall vs. pitch controlled turbines.

Extensive literature searches and reviews were conducted to identify studies that specifically evaluate human population responses to turbines, as well as population and individual responses to the three primary characteristics or attributes of wind turbine operation: noise, vibration, and flicker. An emphasis of the Panel’s efforts was to examine the biological plausibility or basis for health effects of turbines (noise, vibration, and flicker). Beyond traditional forms of scientific publications, the Panel also took great care to review other non-peer reviewed materials regarding the potential for health effects including information related to “Wind Turbine Syndrome” and provides a rigorous analysis as to whether there is scientific basis for it. Since the most commonly reported complaint by people living near turbines is sleep disruption, the Panel provides a robust review of the relationship between noise, vibration, and annoyance as well as sleep disturbance from noises and the potential impacts of the resulting sleep deprivation.

In assessing the state of the evidence for health effects of wind turbines, the Panel followed accepted scientific principles and relied on several different types of studies. It considered human studies of the most important or primary value. These were either human epidemiological studies specifically relating to exposure to wind turbines or, where specific exposures resulting from wind turbines could be defined, the panel also considered human experimental data. Animal studies are critical to exploring biological plausibility and understanding potential biological mechanisms of different exposures, and for providing information about possible health effects when experimental research in humans is not ethically or practically possible. As such, this literature was also reviewed with respect to wind turbine exposures. The non-peer reviewed material was considered part of the weight of evidence. In all cases, data quality was considered; at times, some studies were rejected because of lack of rigor or the interpretations were inconsistent with the scientific evidence.

ES 4. Findings

The findings in Chapter 4 are repeated here.

Based on the detailed review of the scientific literature and other available reports and consideration of the strength of scientific evidence, the Panel presents findings relative to three factors associated with the operation of wind turbines: noise and vibration, shadow flicker, and ice throw. The findings that follow address specifics in each of these three areas.

ES 4.1 Noise

ES 4.1.a Production of Noise and Vibration by Wind Turbines

1. Wind turbines can produce unwanted sound (referred to as noise) during operation. The nature of the sound depends on the design of the wind turbine. Propagation of the sound is primarily a function of distance, but it can also be affected by the placement of the turbine, surrounding terrain, and atmospheric conditions.
    a. Upwind and downwind turbines have different sound characteristics, primarily due to the interaction of the blades with the zone of reduced wind speed behind the tower in the case of downwind turbines.
    b. Stall regulated and pitch controlled turbines exhibit differences in their dependence of noise generation on the wind speed
    c. Propagation of sound is affected by refraction of sound due to temperature gradients, reflection from hillsides, and atmospheric absorption. Propagation effects have been shown to lead to different experiences of noise by neighbors.
    d. The audible, amplitude-modulated noise from wind turbines (“whooshing”) is perceived to increase in intensity at night (and sometimes becomes more of a “thumping”) due to multiple effects: i) a stable atmosphere will have larger wind gradients, ii) a stable atmosphere may refract the sound downwards instead of upwards, iii) the ambient noise near the ground is lower both because of the stable atmosphere and because human generated noise is often lower at night.

2. The sound power level of a typical modern utility scale wind turbine is on the order of 103 dB(A), but can be somewhat higher or lower depending on the details of the design and the rated power of the turbine. The perceived sound decreases rapidly with the distance from the wind turbines. Typically, at distances larger than 400 m, sound pressure levels for modern wind turbines are less than 40 dB(A), which is below the level associated with annoyance in the epidemiological studies reviewed.
3. Infrasound refers to vibrations with frequencies below 20 Hz. Infrasound at amplitudes over 100–110 dB can be heard and felt. Research has shown that vibrations below these amplitudes are not felt. The highest infrasound levels that have been measured near turbines and reported in the literature near turbines are under 90 dB at 5 Hz and lower at higher frequencies for locations as close as 100 m.
4. Infrasound from wind turbines is not related to nor does it cause a “continuous whooshing.”
5. Pressure waves at any frequency (audible or infrasonic) can cause vibration in another structure or substance. In order for vibration to occur, the amplitude (height) of the wave has to be high enough, and only structures or substances that have the ability to receive the wave (resonant frequency) will vibrate.

ES 4.1.b Health Impacts of Noise and Vibration

1. Most epidemiologic literature on human response to wind turbines relates to self-reported “annoyance,” and this response appears to be a function of some combination of the sound itself, the sight of the turbine, and attitude towards the wind turbine project.
    a. There is limited epidemiologic evidence suggesting an association between exposure to wind turbines and annoyance.
    b. There is insufficient epidemiologic evidence to determine whether there is an association between noise from wind turbines and annoyance independent from the effects of seeing a wind turbine and vice versa.

2. There is limited evidence from epidemiologic studies suggesting an association between noise from wind turbines and sleep disruption. In other words, it is possible that noise from some wind turbines can cause sleep disruption.
3. A very loud wind turbine could cause disrupted sleep, particularly in vulnerable populations, at a certain distance, while a very quiet wind turbine would not likely disrupt even the lightest of sleepers at that same distance. But there is not enough evidence to provide particular sound-pressure thresholds at which wind turbines cause sleep disruption. Further study would provide these levels.
4. Whether annoyance from wind turbines leads to sleep issues or stress has not been sufficiently quantified. While not based on evidence of wind turbines, there is evidence that sleep disruption can adversely affect mood, cognitive functioning, and overall sense of health and well-being.
5. There is insufficient evidence that the noise from wind turbines is *directly (i.e., independent from an effect on annoyance or sleep)* causing health problems or disease.
6. Claims that infrasound from wind turbines directly impacts the vestibular system have not been demonstrated scientifically. Available evidence shows that the infrasound levels near wind turbines cannot impact the vestibular system.
    a. The measured levels of infrasound produced by modern upwind wind turbines at distances as close as 68 m are well below that required for non-auditory perception (feeling of vibration in parts of the body, pressure in the chest, etc.).
    b. If infrasound couples into structures, then people inside the structure could feel a vibration. Such structural vibrations have been shown in other applications to lead to feelings of uneasiness and general annoyance. The measurements have shown no evidence of such coupling from modern upwind turbines.
    c. Seismic (ground-carried) measurements recorded near wind turbines and wind turbine farms are unlikely to couple into structures.
    d. A possible coupling mechanism between infrasound and the vestibular system (via the Outer Hair Cells (OHC) in the inner ear) has been proposed but is not yet fully understood or sufficiently explained. Levels of infrasound near wind turbines have been shown to be high enough to be sensed by the OHC. However, evidence does not

exist to demonstrate the influence of wind turbine-generated infrasound on vestibular-mediated effects in the brain.

   e. Limited evidence from rodent (rat) laboratory studies identifies short-lived biochemical alterations in cardiac and brain cells in response to short exposures to emissions at 16 Hz and 130 dB. These levels exceed measured infrasound levels from modern turbines by over 35 dB.

7. There is no evidence for a set of health effects, from exposure to wind turbines that could be characterized as a "Wind Turbine Syndrome."
8. The strongest epidemiological study suggests that there is not an association between noise from wind turbines and measures of psychological distress or mental health problems. There were two smaller, weaker, studies: one did note an association, one did not. Therefore, we conclude the weight of the evidence suggests no association between noise from wind turbines and measures of psychological distress or mental health problems.
9. None of the limited epidemiological evidence reviewed suggests an association between noise from wind turbines and pain and stiffness, diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, and headache/migraine.

ES 4.2 Shadow Flicker

ES 4.2.a Production of Shadow Flicker

Shadow flicker results from the passage of the blades of a rotating wind turbine between the sun and the observer.

1. The occurrence of shadow flicker depends on the location of the observer relative to the turbine and the time of day and year.
2. Frequencies of shadow flicker elicited from turbines is proportional to the rotational speed of the rotor times the number of blades and is generally between 0.5 and 1.1 Hz for typical larger turbines.
3. Shadow flicker is only present at distances of less than 1400 m from the turbine.

ES 4.2.b Health Impacts of Shadow Flicker

1. Scientific evidence suggests that shadow flicker does not pose a risk for eliciting seizures as a result of photic stimulation.

2. There is limited scientific evidence of an association between annoyance from prolonged shadow flicker (exceeding 30 minutes per day) and potential transitory cognitive and physical health effects.

ES 4.3 Ice Throw

ES 4.3.a Production of Ice Throw

Ice can fall or be thrown from a wind turbine during or after an event when ice forms or accumulates on the blades.

1. The distance that a piece of ice may travel from the turbine is a function of the wind speed, the operating conditions, and the shape of the ice.
2. In most cases, ice falls within a distance from the turbine equal to the tower height, and in any case, very seldom does the distance exceed twice the total height of the turbine (tower height plus blade length).

ES 4.3.b Health Impacts of Ice Throw

1. There is sufficient evidence that falling ice is physically harmful and measures should be taken to ensure that the public is not likely to encounter such ice.

ES 4.4 Other Considerations

In addition to the specific findings stated above for noise and vibration, shadow flicker and ice throw, the Panel concludes the following:

1. Effective public participation in and direct benefits from wind energy projects (such as receiving electricity from the neighboring wind turbines) have been shown to result in less annoyance in general and better public acceptance overall.

ES 5. Best Practices Regarding Human Health Effects of Wind Turbines

The best practices presented in Chapter 5 are repeated here.

Broadly speaking, the term “best practice” refers to policies, guidelines, or recommendations that have been developed for a specific situation. Implicit in the term is that the practice is based on the best information available at the time of its institution. A best practice may be refined as more information and studies become available. The panel recognizes that in countries which are dependent on wind energy and are protective of public health, best practices have been developed and adopted.

In some cases, the weight of evidence for a specific practice is stronger than it is in other cases. Accordingly, best practice* may be categorized in terms of the evidence available, as follows:

Descriptions of Three Best Practice Categories

Category	**Name**	**Description**
1	Research Validated Best Practice	A program, activity, or strategy that has the highest degree of proven effectiveness supported by objective and comprehensive research and evaluation.
2	Field Tested Best Practice	A program, activity, or strategy that has been shown to work effectively and produce successful outcomes and is supported to some degree by subjective and objective data sources.
3	Promising Practice	A program, activity, or strategy that has worked within one organization and shows promise during its early stages for becoming a best practice with long-term sustainable impact. A promising practice must have some objective basis for claiming effectiveness and must have the potential for replication among other organizations.

**These categories are based on those suggested in "Identifying and Promoting Promising Practices." Federal Register, Vol. 68. No 131. 131. July 2003.*
www.acf.hhs.gov/programs/ccf/about_ccf/gbk_pdf/pp_gbk.pdf

ES 5.1 Noise

Evidence regarding wind turbine noise and human health is limited. There is limited evidence of an association between wind turbine noise and both annoyance and sleep disruption, depending on the sound pressure level at the location of concern. However, there are no research-based sound pressure levels that correspond to human responses to noise. A number of countries that have more experience with wind energy and are protective of public health have developed guidelines to minimize the possible adverse effects of noise. These guidelines consider time of day, land use, and ambient wind speed. The table below summarizes the guidelines of Germany (in the categories of industrial, commercial and villages) and Denmark (in the categories of sparsely populated and residential). The sound levels shown in the table are for nighttime and are assumed to be taken immediately outside of the residence or building of concern. In addition, the World Health Organization recommends a maximum nighttime sound pressure level of 40 dB(A) in residential areas. Recommended setbacks corresponding to these values may be calculated by software such as WindPro or similar software. Such calculations are normally to be done as part of feasibility studies. The Panel considers the guidelines shown below to be Promising Practices (Category 3) but to embody some aspects of Field Tested Best Practices (Category 2) as well.

Promising Practices for Nighttime Sound Pressure Levels by Land Use Type

Land Use	**Sound Pressure Level, dB(A) Nighttime Limits**
Industrial	70
Commercial	50
Villages, mixed usage	45
Sparsely populated areas, 8 m/s wind*	44
Sparsely populated areas, 6 m/s wind*	42
Residential areas, 8 m/s wind*	39
Residential areas, 6 m/s wind*	37

**measured at 10 m above ground, outside of residence or location of concern*

The time period over which these noise limits are measured or calculated also makes a difference. For instance, the often-cited World Health Organization recommended nighttime noise cap of 40 dB(A) is averaged over one year (and does not refer specifically to wind turbine noise). Denmark’s noise limits in the table above are calculated over a 10-minute period. These limits are in line with the noise levels that the epidemiological studies connect with insignificant reports of annoyance.

The Panel recommends that noise limits such as those presented in the table above be included as part of a statewide policy regarding new wind turbine installations. In addition, suitable ranges and procedures for cases when the noise levels may be greater than those values should also be considered. The considerations should take into account trade-offs between environmental and health impacts of different energy sources, national and state goals for energy independence, potential extent of impacts, etc.

The Panel also recommends that those involved in a wind turbine purchase become familiar with the noise specifications for the turbine and factors that affect noise production and noise control. Stall and pitch regulated turbines have different noise characteristics, especially in high winds. For certain turbines, it is possible to decrease noise at night through suitable control measures (e.g., reducing the rotational speed of the rotor). If noise control measures are to be considered, the wind turbine manufacturer must be able to demonstrate that such control is possible.

The Panel recommends an ongoing program of monitoring and evaluating the sound produced by wind turbines that are installed in the Commonwealth. IEC 61400-11 provides the standard for making noise measurements of wind turbines (International Electrotechnical Commission, 2002). In general, more comprehensive assessment of wind turbine noise in populated areas is recommended. These assessments should be done with reference to the broader ongoing research in wind turbine noise production and its effects, which is taking place internationally. Such assessments would be useful for refining siting guidelines and for developing best practices of a higher category. Closer investigation near homes where outdoor measurements show A and C weighting differences of greater than 15 dB is recommended.

ES 5.2 Shadow Flicker

Based on the scientific evidence and field experience related to shadow flicker, Germany has adopted guidelines that specify the following:

1. Shadow flicker should be calculated based on the astronomical maximum values (i.e., not considering the effect of cloud cover, etc.).
2. Commercial software such as WindPro or similar software may be used for these calculations. Such calculations should be done as part of feasibility studies for new wind turbines.
3. Shadow flicker should not occur more than 30 minutes per day and not more than 30 hours per year at the point of concern (e.g., residences).
4. Shadow flicker can be kept to acceptable levels either by setback or by control of the wind turbine. In the latter case, the wind turbine manufacturer must be able to demonstrate that such control is possible.

The guidelines summarized above may be considered to be a Field Tested Best Practice (Category 2). Additional studies could be performed, specifically regarding the number of hours per year that shadow flicker should be allowed, that would allow them to be placed in Research Validated (Category 1) Best Practices.

ES 5.3 Ice Throw

Ice falling from a wind turbine could pose a danger to human health. It is also clear that the danger is limited to those times when icing occurs and is limited to relatively close proximity to the wind turbine. Accordingly, the following should be considered Category 1 Best Practices.

1. In areas where icing events are possible, warnings should be posted so that no one passes underneath a wind turbine during an icing event and until the ice has been shed.
2. Activities in the vicinity of a wind turbine should be restricted during and immediately after icing events in consideration of the following two limits (in meters).

For a turbine that may not have ice control measures, it may be assumed that ice could fall within the following limit:

$$x_{\max,\,throw} = 1.5\left(2R + H\right)$$

Where: R = rotor radius (m), H = hub height (m)

For ice falling from a stationary turbine, the following limit should be used:

$$x_{\max,\,fall} = U\left(R + H\right)/15$$

Where: U = maximum likely wind speed (m/s)

The choice of maximum likely wind speed should be the expected one-year return maximum, found in accordance to the International Electrotechnical Commission’s design standard for wind turbines, IEC 61400-1.

Danger from falling ice may also be limited by ice control measures. If ice control measures are to be considered, the wind turbine manufacturer must be able to demonstrate that such control is possible.

ES 5.4 Public Participation/Annoyance

There is some evidence of an association between participation, economic or otherwise, in a wind turbine project and the annoyance (or lack thereof) that affected individuals may express. Accordingly, measures taken to directly involve residents who live in close proximity to a wind turbine project may also serve to reduce the level of annoyance. Such measures may be considered to be a Promising Practice (Category 3).

ES 5.5 Regulations/Incentives/Public Education

The evidence indicates that in those parts of the world where there are a significant number of wind turbines in relatively close proximity to where people live, there is a close coupling between the development of guidelines, provision of incentives, and educating the public. The Panel suggests that the public be engaged through such strategies as education, incentives for community-owned wind developments, compensations to those experiencing documented loss of property values, comprehensive setback guidelines, and public education related to renewable energy. These multi-faceted approaches may be considered to be a Promising Practice (Category 3).

Chapter 1

Introduction to the Study

The Massachusetts Department of Environmental Protection (MassDEP), in collaboration with the Massachusetts Department of Public Health (MDPH), convened a panel of independent experts to identify any documented or potential health impacts or risks that may be associated with exposure to wind turbines, and, specifically, to facilitate discussion of wind turbines and public health based on sound science. While the Commonwealth of Massachusetts has goals for increasing the use of wind energy from the current 40 MW to 2000 MW by the year 2020, MassDEP recognizes there are questions and concerns arising from harnessing wind energy. Although fossil fuel non-renewable sources have negative environmental and health impacts, it should be noted that the scope of the Panel's effort was focused on wind turbines and is not meant to be a comparative analysis of the relative merits of wind energy vs. nonrenewable fossil fuel sources such as coal, oil, and natural gas. Currently, "regulation" of wind turbines is done at the local level through local boards of health and zoning boards. Some members of the public have raised concerns that wind turbines may have health impacts related to noise, infrasound, vibrations, or shadow flickering generated by the turbines. The goal of the Panel's evaluation and report is to provide a review of the science that explores these concerns and provides useful information to MassDEP and MDPH and to local agencies who are often asked to respond to such concerns.

The overall context for this study is that the use of wind turbines results in positive effects on public health and environmental health. For example, wind turbines operating in Massachusetts produce electricity in the amount of approximately 2,100–2,900 MWh annually per rated MW, depending on the design of the turbine and the average wind speed at the installation site. Furthermore, the use of wind turbines for electricity production in the New England electrical grid will result in a significant decrease in the consumption of conventional fuels and a corresponding decrease in the production of CO_2 and oxides of nitrogen and sulfur (see Appendix A for details). Reductions in the production of these pollutants will have demonstrable and positive benefits on human and environmental health. However, local impacts of wind turbines, whether anticipated or demonstrated, have resulted in fewer turbines being installed than might otherwise have been expected. To the extent that these impacts can be ameliorated, it should be possible to take advantage of the indigenous wind energy resource more effectively.

The Panel consists of seven individuals with backgrounds in public health, epidemiology, toxicology, neurology and sleep medicine, neuroscience, and mechanical engineering. With the exception of two individuals (Drs. Manwell and Mills), Panel members did not have any direct experience with wind turbines. The Panel did an extensive literature review of the scientific literature (see bibliography) as well as other reports, popular media, and the public comments received by the MassDEP.

Chapter 2

Introduction to Wind Turbines

This chapter provides an introduction to wind turbines so as to provide a context for the discussion that follows. More information on wind turbines may be found in the appendices, particularly in Appendix A.

2.1 Wind Turbine Anatomy and Operation

Wind turbines utilize the wind, which originates from sunlight due to the differential heating of various parts of the earth. This differential heating produces zones of high and low pressure, resulting in air movement. The motion of the air is also affected by the earth's rotation. Many countries have turned to wind power as a clean energy source because it relies on the wind, which is indefinitely renewable; it is generated "locally," thereby providing a measure of energy independence; and it produces no carbon dioxide emissions when operating. There is interest in pursuing wind energy both on-land and offshore. For this report, however, the focus is on land-based installations, and all comments will focus on this technology.

The development of modern wind turbines has been an evolutionary design process, applying optimization at many levels. This section gives a brief overview of the characteristics of wind turbines with some mention of the optimization parameters of interest. Appendix A provides a detailed explanation of wind energy.

The main features of modern wind turbines one notices are the very tall towers, which are no longer a lattice structure but a single cylindrical-like structure and the three upwind, very long, highly contoured turbine blades. The tower design has evolved partly because of biological impact factors as well as for other practical reasons. The early lattice towers were attractive nesting sites for birds. This led to an unnecessary impact of wind turbines on bird populations. The lattice structures also had to be climbed externally by turbine technicians. The tubular towers, which are now more common, are climbed internally. This reduces the health risks for maintenance crews.

The power in the wind available to a wind turbine is related to the cube of the wind speed and the square of the radius of the rotor. Not all the available power in the wind can be captured by a wind turbine, however. Betz (van Kuik, 2007) showed that the maximum power that can be extracted is 16/27 times the available power (see Appendix A). In an attempt to extract the maximum power from the wind, modern turbines have very large rotors and the towers are quite high. In this way the dependence on the radius is “optimized,” and the dependence on the wind speed is “optimized.” The wind speed is higher away from the ground due to boundary layer effects, and as such, the towers are made higher in order to capture the higher speed winds (more information about the wind profiles and variability is found in Appendix A). It is noted here that the rotor radius may increase again in the future, but currently the largest rotors used on land are around 100 m in diameter. This upper limit is currently a function of the radius of curvature of the roads on which the trucks that deliver the turbine blades must drive to the installation sites. Clearance under bridges is also a factor.

The efficiency with which the wind’s power is captured by a particular wind turbine (i.e., how close it comes to the Betz limit) is a function of the blade design, the gearbox, the electrical generator, and the control system. The aerodynamic forces on the rotor blade play a major role. The best design maximizes lift and minimizes drag at every blade section from hub to tip. The twisted and tapered shapes of modern blades attempt to meet this optimal condition. Other factors also must be taken into consideration such as structural strength, ease of manufacturing and transport, type of materials, cost, etc.

Beyond these visual features, the number of blades and speed of the tips play a role in the optimization of the performance through what is called solidity. When setting tip speeds based on number of blades, however, trade-offs exist because of the influence of these parameters on weight, cost, and noise. For instance, higher tip speeds often results in more noise.

The dominance of the 3-bladed upwind systems is both historic and evolutionary. The European manufacturers moved to 3-bladed systems and installed numerous turbines, both in Europe and abroad. Upwind systems are preferable to downwind systems for on-land installations because they are quieter. The downwind configuration has certain useful features but it suffers from the interaction noise created when the blades pass through the wake that forms behind the tower.

The conversion of the kinetic energy of the wind into electrical energy is handled by the rotor nacelle assembly (RNA), which consists of the rotor, the drive train, and various ancillary components. The rotor grouping includes the blades, the hub, and the pitch control components. The drive train includes the shafts, bearings, gearbox (not necessary for direct drive generators), couplings, mechanical brake, and generator. A schematic of the RNA, together with more detail concerning the operation of the various parts, is in Appendix A.

The rotors are controlled so as to generate electricity most effectively and as such must withstand continuously fluctuating forces during normal operation and extreme loads during storms. Accordingly, in general a wind turbine rotor does not operate at its own maximum power coefficient at all wind speeds. Because of this, the power output of a wind turbine is generally described by a relationship, known as a power curve. A typical power curve is shown in the appendix. Below the cut-in speed no power is produced. Between cut-in and rated wind speed the power increases significantly with wind speed. Above the rated speed, the power produced is constant, regardless of the wind speed, and above the cut-out speed the turbine is shut down often with use of the mechanical brake.

Two main types of rotor control systems exist: pitch and stall. Stall controlled turbines have fixed blades and operate at a fixed speed. The aerodynamic design of the blades is such that the power is self-limiting, as long as the generator is connected to the electrical grid. Pitch regulated turbines have blades that can be rotated about their long axis. Such an arrangement allows more precise control. Pitch controlled turbines are also generally quieter than stall controlled turbines, especially at higher wind speeds. Until recently, many turbines used stall control. At present, most large turbines use pitch control. Appendices A and F provide more details on pitch and stall.

The energy production of a wind turbine is usually considered annually. Estimates are usually obtained by calculating the expected energy that will be produced every hour of a representative year (by considering the turbine’s power curve and the estimated wind resource) and then summing the energy from all the hours. Sometimes a normalized term known as the capacity factor (CF) is used to characterize the performance. This is the actual energy produced (or estimated to be produced) divided by the amount of energy that would be produced if the turbine were running at its rated output for the entire year. Appendix A gives more detail on these computations.

2.2 Noise from Turbines

Because of the concerns about the noise generated from wind turbines, a short summary of the sources of noise is provided here. A thorough description of the various noise sources from a wind turbine is given in the text by Wagner et al. (1996).

A turbine produces noise mechanically and aerodynamically. Mechanical noise sources include the gearbox, generator, yaw drives, cooling fans, and auxiliary equipment such as hydraulics. Because the emitted sound is associated with the rotation of mechanical and electrical equipment, it is often tonal. For instance, it was found that noise associated with a 1500 kW turbine with a generator running at speeds between 1100 and 1800 rpm contained a tone between 20 and 30 Hz (Betke et al., 2004). The yaw system on the other hand might produce more of a grinding type of noise but only when the yaw mechanism is engaged. The transmission of mechanical noise can be either airborne or structure-borne as the associated vibrations can be transmitted into the hub and tower and then radiated into the surrounding space.

Advances in gearboxes and yaw systems have decreased these noise sources over the years. Direct drive systems will improve this even more. In addition, utility scale wind turbines are usually insulated to prevent mechanical noise from proliferating outside the nacelle or tower (Alberts, 2006)

Aerodynamic sound is generated due to complex fluid-structure interactions occurring on the blades. Wagner et al. (1996) break down the sources of aerodynamic sound as follows in Table 1.

Table 1

Sources of Aerodynamic Sound from a Wind Turbine (Wagner et al., 1996*)*.

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

**van den Berg 2004.*

Of these mechanisms, the most persistent and often strongest source of aerodynamic sound from modern wind turbines is the trailing edge noise. It is also the amplitude modulation of this noise source due to the presence of atmospheric effects and directional propagation effects that result in the whooshing or beating sound often reported (van den Berg, 2004). As a turbine blade rotates through a changing wind stream, the aerodynamics change, leading to differences in the boundary layer and thus to differences in the trailing edge noise (Oerlemans, 2009). Also, the direction in which the blade is pointing changes as it rotates, leading to differences in the directivity of the noise from the trailing edge. This noise source leads to what some people call the "whooshing" sound.

Most modern turbines use pitch control for a variety of reasons. One of the reasons is that at higher wind speeds, when the control system has the greatest impact, the pitch controlled turbine is quieter than a comparable stall regulated turbine would be. Appendix E shows the difference in the noise from two such systems.

When discussing noise from turbines, it is important to also consider propagation effects and multiple turbine effects. One propagation effect of interest is due to the dependence of the speed of sound on temperature. When there is a large temperature gradient (which may occur during the day due to surface warming or due to topography such as hills and valleys) the path a sound wave travels will be refracted. Normally this means that during a typical day sound is "turned" away from the earth's surface. However, at night the sound propagates at a constant height or even be "turned" down toward the earth's surface, making it more noticeable than it otherwise might be.

The absorption of sound by vegetation and reflection of sound from hillsides are other propagation effects of interest. Several of these effects were shown to be influencing the sound field near a few homes in North Carolina that were impacted by a wind turbine installation (Kelley et al., 1985). A downwind 2-bladed, 2 MW turbine was installed on a mountaintop in North Carolina. It created high amplitude impulsive noise due to the interaction of the blades and the tower wakes. Some homes (10 in 1000) were adversely affected by this high amplitude impulsive noise. It is shown in the report by Kelley et al. (1985) that echoes and focusing due to refraction occurred at the location of the affected homes.

In flat terrain, noise in the audible range will propagate along a flat terrain in a manner such that its amplitude will decay exactly as distance from the source (1/distance). Appendix E provides formulae for approximating the overall sound level at a given distance from a source. In the inaudible range, it has been noted that often the sound behaves as if the propagation was governed by a $1/(\text{distance})^{1/2}$ (Shepherd & Hubbard, 1991).

When one considers the noise from a wind farm in which multiple turbines are located close to each other, an estimate for the overall noise from the farm can be obtained. Appendix E describes the method for obtaining the estimate. All these estimates rely on information regarding the sound power generated by the turbine at the hub height. The power level for several modern turbines is given in Appendix D.

2.2.a Measurement and Reporting of Noise

Turbines produce multiple types of sound as indicated previously, and the sound is characterized in several ways: tonal or broadband, constant amplitude or amplitude modulated, and audible or infrasonic. The first two characterization pairs have been mentioned previously. Audible refers to sound with frequencies from 20 Hz to 20 kHz. The waves in the infrasonic range, less than 20 Hz, may actually be audible if the amplitude of the sound is high enough. Appendix D provides a brief primer on acoustics and the hearing threshold associated with the entire frequency spectrum.

Sound is simply pressure fluctuations and as such, this is what a microphone measures. However, the amplitude of the fluctuations is reported not in units of pressure (such as Pascals) but on a decibel scale. The sound pressure level (SPL) is defined by

$$\text{SPL} = 10 \log_{10} [p^2/p^2_{\text{ref}}] = 20 \log_{10}(p/p_{\text{ref}})$$

the resulting number having the units of decibels (dB). The reference pressure p_{ref} for airborne sound is 20×10^{-6} Pa (i.e., 20 μPa or 20 micro Pascals). Some implications of the decibel scale are noted in Appendix D.

When sound is broadband (contains multiple frequencies), it is useful to use averages that measure approximately the amplitude of the sound and its frequency content. Standard averaging methods such as octave and 1/3-octave band are described in Appendix D. In essence, the entire frequency range is broken into chunks, and the amplitude of the sound at frequencies in each chunk is averaged. An overall sound pressure value can be obtained by averaging all of the bands.

When presenting the sound pressure it is common to also use a filter or weighting. The A-weighting is commonly used in wind turbine measurements. This filter takes into account the threshold of human hearing and gives the same decibel reading at different frequencies that would equate to equal loudness. This means that at low frequencies (where amplitudes have to be incredibly high for the sound to be heard by people) a large negative weight would be applied. C-weighting only filters the levels at frequencies below about 30 Hz and above 4 kHz and filters them only slightly between 0 and 30 Hz. The weight values for both the A and C weightings filters are shown in Appendix D, and an example with actual wind turbine data is presented.

There are many other weighting methods. For instance, the day-night level filter penalizes nighttime noise between the hours of 10 p.m. and 7 a.m. by adding an additional 10 dB to sound produced during these hours.

When analyzing wind turbine and other anthropogenic sound there is a question as to what averaging period should be used. The World Health Organization uses a yearly average. Others argue though that especially for wind turbines, which respond to seasonal variations as well as diurnal variations, much shorter averages should be considered.

2.2.b Infrasound and Low-frequency Noise (IFLN)

The term *infrasound* refers to pressure waves with frequencies less than 20 Hz. In the infrasonic range, the amplitude of the sound must be very high for it to be audible to humans. For instance, the hearing threshold below 20 Hz requires that the amplitude be above 80 dB for it to be heard and at 5 Hz it has to be above 103 dB (O’Neal, 2011; Watanabe & Moeller, 1990). This gives little room between the audible and the pain values for the infrasound range: 165 dB at 2 Hz and 145 dB at 20 Hz cause pain (Leventhal, 2006).

The *low frequency* range is usually characterized as 20–200 Hz (Leventhal, 2006; O’Neal, 2011). This is within the audible range but again the threshold of hearing indicates that fairly high amplitude is required in this frequency range as well. The A-weighting of sound is based upon the threshold of human hearing such that it reports the measured values adjusted by -50 dB at 20 Hz, -10 dB at 200 Hz, and + 1 dB at 1000 Hz. The A-weighting curve is shown in Appendix D.

It is known that low frequency waves propagate with less attenuation than high-frequency waves. Measurements have shown that the amplitude for the airborne infrasonic waves can be cylindrical in nature, decaying at a rate inversely proportional to the square root of the distance from the source. Normally the decay of the amplitude of an acoustic wave is inversely proportional to the distance (Shepherd & Hubbard, 1991).

It is difficult to find reliable and comparable infrasound and low frequency noise (ILFN) measurement data in the peer-reviewed literature. Table 2 provides some examples of such measurements from wind turbines. For each case, the reliability of the infrasonic data is not known (the infrasonic measurement technique is not described in each report), although it is assumed that the low frequency noise was captured accurately. The method for obtaining the sound pressure level is not described for each reported data set, and some may come from averages over many day/time/wind conditions while others may be just from a single day's measurement campaign.

Table 2
Literature-based Measurements of Wind Turbines; dB alone refers to unweighted values

Turbine Rating (kW)	**Distance (m)**	**Frequency**	**Sound Pressure Level**	**Reference**
500	200	5 20	55 dB(G)[2] 35 dB(G)[2]	Jakobsen, 2005[3]
3200	68	4 20	72 dB(G)[2] 50 dB(G)[2]	Jakobsen, 2005[3]
1500	65	5 20 100	>70 dB(A) 60 dB(A) 35 dB(A)	Leventhal, 2006
2000 (2)	100	5 20 200	95 dB 65 dB 55 dB	van den Berg, 2004[3]
1500	98	1 10 20 100 200	90 dB 70 dB 68 dB 68 dB 60 dB	Jung, 2008[3]
-	450	10 100 200	75 dB 55 dB 40 dB	Palmer, 2010
2300	305	5 20 100	73 dB(A) 55 dB(A) - 95 50 dB(A) - 70	O'Neal, 2011[3]

[1] dB alone refers to un-weighted values.
[2] G weighting reflects human response to infrasound. The curve is defined to have a gain of zero dB at 10 Hz. Between 1 Hz and 20 Hz the slope is approximately 12 dB per octave. The cut-off below 1 Hz has a slope of 24 dB per octave, and above 20 Hz the slope is -24 dB per octave. Humans can hear 95 dB(G).
[3] Indicates peer-reviewed article.

When these recorded levels are taken at face value, one might conclude that the infrasonic regime levels are well below the audible threshold. In contrast, the low frequency regime becomes audible around 30 Hz. Such data have led many researchers to conclude that the infrasound and low frequency noise from wind turbines is not an issue (Leventhal, 2009; O'Neal, 2011; Bowdler, 2009). Others who have sought explanations for complaints from those living near wind turbines have pointed to ILFN as a problem (Pierpont, 2009; Branco & Alves-

Pereira, 2004). Some have declared the low frequency range to be of greatest concern (Kamperman et al., 2008; Jung, 2008).

It is important to make the clear distinction between amplitude-modulated noise from wind turbines and the ILFN from turbines. Amplitude modulation in wind turbines noise has been discussed at length by Oerlemans (2009) and van den Berg (2004). Amplitude modulation is what causes the whooshing sound referred to as swish-swish by van den Berg (that sometimes becomes a thumping sound). The whooshing noise created by modern wind turbines occurs because of variations in the trailing edge noise produced by a rotor blade as it sweeps through its path and the directionality of the noise because of the perceived pitch of the blade at different locations along its 360° rotation. The sound is produced in the audible range, and it is modulated so that it is quiet and then loud and then quiet again at a rate related to the blade passing frequency (rate blades pass the tower) which is often around 1 Hz. Van den Berg (2004) noted that the level of amplitude modulation is often greater at night because the difference between the wind speed at the top and bottom of the rotor disc can be much larger at night when there is a stable atmosphere than during the day when the wind profile is less severe. It is further argued that in a stable atmosphere there is little wind near the ground so wind noise does not mask the turbine noise for a listener near the ground. Finally, atmospheric effects can change the propagation of the sound refracting the noise towards the ground rather than away from the ground. The whooshing that is heard is NOT infrasound and much of its content is not at low frequency. Most of the sound is at higher frequency and as such it will be subject to higher atmospheric attenuation than the low frequency sound. An anecdotal finding that the whooshing sound carries farther when the atmosphere is stable does not imply that it is infrasound or heavy in low frequency content, it simply implies that the refraction of the sound is also different when the atmosphere is stable. It is important to note then that when a complaint is tied to the thumping or whooshing that is being heard, the complaint may not be about ILFN at all even if the complaint mentions low frequency noise. Kamperman et al. (2008) state that, "It is not clear to us whether the complaints about "low frequency" noise are about the audible low frequency part of the "swoosh-boom" sound, the once-per-second amplitude modulation … of the "swoosh-boom" sound, or some combination of the two."

Chapter 3

Health Effects

3.1 Introduction

Chapter 3 reviews the evidence for human health effects of wind turbines. Extensive literature searches and reviews were conducted to identify studies that specifically evaluate population responses to turbines, as well as population and individual responses to noise, vibration, and flicker. The biological plausibility or basis for health effects of turbines (noise, vibration, and flicker) was examined. Beyond traditional forms of scientific publications, the Panel also reviewed other non-peer reviewed materials including information related to "Wind Turbine Syndrome" and provides a rigorous analysis of its scientific basis. Since the most commonly reported complaint by people living near turbines is sleep disruption, the Panel provides a robust review of the relationship between noise, vibration, annoyance as well as sleep disturbance from noises and the potential impacts of the resulting sleep deprivation.

In assessing the state of the evidence for health effects of wind turbines, the Panel relied on several different types of studies. It considered human studies of primary value. These were either human epidemiological studies specifically relating to exposure to wind turbines or, where specific exposures resulting from wind turbines could be defined, the Panel also considered human experimental data. Animal studies are critical to exploring biological plausibility and understanding potential biological mechanisms of different exposures, and for providing information about possible health effects when experimental research in humans is not ethically or practically possible (National Research Council (NRC), 1991). As such, this literature was also reviewed with respect to wind turbine exposures. In all cases, data quality is considered. At times some studies were rejected because of lack of rigor or the interpretations were inconsistent with the scientific evidence. These are identified in the discussion below.

In the specific case of the possibility of ice being thrown from wind turbine blades, the Panel discusses the physics of such ice throw in order to provide the basis of the extent of the potential for injury from thrown ice (see Chapter 2).

3.2 Human Exposures to Wind Turbines

Epidemiologic study designs differ in their ability to provide evidence of an association (Ellwood, 1998). Typical study designs include randomized trials, cohort studies, and case-control studies and can include elements of prospective follow-up, retrospective assessments, or cross-sectional analysis where exposure and outcome data are essentially concurrent. Each of these designs has strengths and weaknesses and thus can provide varying levels of strength of evidence for causal associations between exposures and outcomes, which can also be affected by analytic choices. Thus, this literature needs to be examined in detail, regardless of study type, to determine strength of evidence for causality.

Review of this literature began with a PubMed search for “wind turbine” or “wind turbines” to identify peer-reviewed literature pertaining to health effects of wind turbines. Titles and abstracts of identified papers were then read to make a first pass determination of whether the paper was a study on health effects of exposure to wind turbines or might possibly contain relevant references to such studies. Because the peer-reviewed literature so identified was relatively limited, we also examined several non-peer reviewed papers, reports, and books that discussed health effects of wind turbines. All of this literature was examined for additional relevant references, but for the purposes of determining strength of evidence, we only considered such publications if they described studies of some sort in sufficient detail to assess the validity of the findings. This process identified four studies that generated peer-reviewed papers on health effects of wind turbines. A few other non-peer reviewed documents described data of sufficient relevance to merit consideration and are discussed below as well.

3.3 Epidemiological Studies of Exposure to Wind Turbines

The four studies that generated peer-reviewed papers on health effects of wind turbines included two from Sweden (E. Pedersen et al., 2007; E. Pedersen & Waye, 2004), one from the Netherlands (E. Pedersen et al., 2009), and one from New Zealand (Shepherd at al., 2011). The primary outcome assessed in the first three of these studies is annoyance. Annoyance *per se* is not a biological disease, but has been defined in different ways. For example, as “a feeling of resentment, displeasure, discomfort, dissatisfaction, or offence which occurs when noise interferes with someone’s thoughts, feelings or daily activities” (Passchier-Vermeer, 1993); or “a mental state characterized by distress and aversion, which if maintained, can lead to a deterioration of health and well-being” (Shepherd et al., 2010). Annoyance is usually assessed with questionnaires, and this is the case for the three studies mentioned above. There is consistent evidence for annoyance in populations exposed for more than one year to sound levels of 37 dB(A), and severe annoyance at about 42 dB(A) (Concha-Barrientos et al., 2004). In each of those studies annoyance was assessed by questionnaire, and the respondent was asked to indicate annoyance to a number of items (including wind turbines) on a five-point scale (do not notice, notice but not annoyed, slightly annoyed, rather annoyed, very annoyed). While annoyance as such is certainly not to be dismissed, in assessing global burden of disease the World Health Organization (WHO) has taken the approach of excluding annoyance as an outcome because it is not a formally defined health outcome *per se* (Concha-Barrientos et al., 2004). Rather, to the extent annoyance may cause other health outcomes, those other outcomes could be considered directly. Nonetheless, because of a paucity of literature on the association between wind turbines and other health outcomes, we consider here the literature on wind turbines and annoyance.

3.3.a Swedish Studies

Both Swedish studies were cross sectional and involved mailed questionnaires to potential participants. For the first Swedish study, 627 households were identified in one of five areas of Sweden chosen to have enough dwellings at varying distances from wind turbines and of comparable geographical, cultural, and topographical structure (E. Pedersen & Waye, 2004). There were 16 wind turbines in the study area and of these, 14 had a power of 600–650 kW, and the other 2 turbines had 500 kW and 150 kW. The towers were between 47 and 50 m in height. Of the turbines, 13 were WindWorld machines, 2 were Enercon, and 1 was a Vestas turbine. Questionnaires were to be filled out by one person per household who was between the ages of 18 and 75. If there was more than one such person, the one whose birthday was closest to May 20th was chosen. It is not clear how the specific 627 households were chosen, and of the 627, only 513 potential participants were identified, although it is not clear why the other households did not have potential participants. Of the 513 potential participants, 351 (68.4%) responded.

The purpose of the questionnaire was masked by querying the participant about living conditions in general, some questions on which were related to wind turbines. However, a later section of the questionnaire focused more specifically on wind turbines, and so the degree to which the respondent was unaware about the focus on wind turbines is unclear. A-weighted sound levels were determined at each respondent's dwelling, and these levels were grouped into

6 categories (in dB(A): <30, 30–32.5, 32.5–35, 35–37.5, 37.5–40, and >40). Ninety-three percent of respondents could see a wind turbine from their dwelling.

The main results of this study were that there was a significant association between noise level and annoyance. This association was attenuated when adjusted for the respondent's attitude towards the visual impact of the turbines, which itself was a strong predictor of annoyance levels, but the association with noise still persisted. Further adjustment for noise sensitivity and attitude towards wind turbines in general did not change the results. The authors indicated that the reporting of sleep disturbances went up with higher noise categories, but did not report on the significance of this association. Nor did the authors report on associations with other health-related questions that were apparently on the questionnaire (such as headache, undue tiredness, pain and stiffness in the back, neck or shoulders, or feeling tensed/stressed, or irritable).

The 68% response rate in this study is reasonably good, but it is somewhat disconcerting that the response rate appeared to be higher in the two highest noise level categories (76% and 78% vs. 60–69%). It is not implausible that those who were annoyed by the turbines were more inclined to return the questionnaire. In the lowest two sound categories (<32.5 dB(A)) nobody reported being more than slightly annoyed, whereas in the highest two categories 28% (37.5–40 dB(A)) and 44% (>40 dB(A)) reported being more than slightly annoyed (unadjusted percentages). Assuming annoyance would drive returning the questionnaires, this would suggest that the percentages in the highest categories may be somewhat inflated. The limited description of the selection process in this study is a limitation as well, as is the cross sectional nature of the study. Cross-sectional studies lack the ability to determine the temporality of cause and effect; in the case of these kinds of studies, we cannot know whether the annoyance level was present before the wind turbines were operational from a cross sectional study design. Furthermore, despite efforts to blind the respondent to the emphasis on wind turbines, it is not clear to what degree this was successful.

The second Swedish study (E. Pedersen & Persson Waye, 2007) took a similar approach to the first, but in this study the selection procedures were explained in more detail and were clearly rigorous. Specific details on the wind turbines in the area were not provided, but it was noted that areas were sought with wind turbines that had a nominal power of more than 500 kW, although some of the areas also contained turbines with lower power. A later publication by these authors (Pedersen et al., 2009) indicates that the turbines in this study were up to 1.5 MW and up to 65 m high. In the areas chosen, either all households were recruited or a random sample was used. In this study 1,309 questionnaires were sent out and 754 (57.6%) were returned. The response rate by noise category level, however, was not reported. There was a clear association between noise level and hearing turbine noise, with the percentage of those hearing turbine noise steadily increasing across the noise level categories. However, despite a significant unadjusted association between noise levels and annoyance (dichotomized as more than slightly annoyed or not), and after adjusting for attitude towards wind turbines or visual aspects of the turbines (e.g., visual angle on the horizon, an indicator of how prominent the turbines are in the field of view), each of which was strongly associated with annoyance, the association with noise level category was lost. The model from which this conclusion was drawn, however, imposed a linear relation on the association between noise level category and annoyance. But in the crude percentages of people annoyed across noise level categories, it appeared that the relation might not be linear, but rather most prevalent in the highest noise. The percentage of those in the highest noise level category (>40 dB(A)) reporting annoyance (~15%) appeared to be higher than among people in the lower noise categories (<5%).

Given the more rigorous description of the selection process in this study, it has to be considered stronger than the first Swedish study. While 58% is pretty good for a questionnaire response rate, the non-response levels still leave room for bias. The authors do not report the response rate by noise level categories, but if the pattern is similar to the first Swedish study, it could suggest that the percentage annoyed in the highest noise category could be inflated. The cross sectional nature of the study is also a limitation and complicates interpretation of the effects on the noise-annoyance association of adjustment for the other factors. Regarding the loss of the association after adjustment for attitude, if one assumes that the noise levels caused a negative attitude towards wind turbines, then the loss of association between noise and annoyance after adjusting for attitude does not argue against annoyance being caused by increasing turbine noise, but rather that that is the path by which noise causes annoyance (louder noise→negative attitude→annoyance). If, on the other hand, the attitude towards turbines was not caused by the noise, then the results would suggest that noise levels did not cause the annoyance. Visual angle, however, clearly does not cause the noise level; thus, the lack of association between noise and annoyance in analyses adjusted for visual angle more strongly suggest that the turbine noise level is not causing the annoyance, but perhaps the visual intrusion instead. This is similar to the conclusion of an earlier Danish report (T. H. Pedersen & Nielsen, 1994). Either way, however, the data still suggest that there may be an association between turbine noise and annoyance when the noise levels are >40 dB(A).

A more intricate statistical model of the association between turbine noise levels and annoyance that used the data from both Swedish studies was reported separately (Pedersen & Larsman, 2008). The authors used structural equation models (SEMs) to simultaneously account for several aspects of visual attitude towards the turbines and general attitude towards the turbines. These analyses suggested a significant association between noise levels and annoyance even after considering other factors.

3.3.b Dutch Study

The Dutch study aimed to recruit households that reflected general wind turbine exposure conditions over a range of background sound levels. All areas within the Netherlands that were characterized by one of three clearly defined land-use types—built-up area, rural area with a main road, and rural area without a main road—and that had at least two wind turbines of at least 500 kW within 500 meters of each other were selected for the study. Sites dominated by industry or business were excluded. All addresses within these areas were obtained and classified into one of five wind turbine noise categories (<30, 30–35, 35–40, 40–45, and >45 dB(A)) based on characteristics of nearby wind turbines, measurements of sound from those turbines, and the International Standards Organization (ISO) standard model of wind turbine noise propagation. Individual households were randomly selected for recruitment within noise/land type categories, except for the highest noise level for which all households were selected because of the small number exposed at the wind turbine noise levels of the highest category.

As with the Swedish studies, the Dutch study was cross sectional and involved a mailed questionnaire modeled on the one used in the Swedish studies. Of 1,948 mailed surveys, 725 (37%) were returned. There was only minor variation in response rate by turbine noise category, although unlike the Swedish studies, the response rate was slightly lower in the higher noise categories. A random sample of 200 non-responders was sent an abbreviated questionnaire asking only two questions about annoyance from wind turbine noise. There was no difference in the distribution of answers to these questions among these non-responders and those who responded to the full questionnaire.

One of the more dramatic findings of this study was that among people who benefited economically from the turbines (n=100; 14%)—who were much more commonly in the higher noise categories—there was virtually no annoyance (3%) despite the same pattern of noticing the noise as those who did not benefit economically. It is possible that this is because attitude towards turbines drives annoyance, but it was also suggested that those who benefit economically are able to turn off the turbines when they become annoying. However, it is not clear how many of those who benefited economically actually had that level of control over the turbines.

Similarly, there was very little annoyance among people who could not see a wind turbine from their residence even when those people were in higher noise categories (although none were in the highest category). In models that adjusted for visibility of wind turbines and economic benefit, sound level was still a significant predictor of annoyance. However, because of the way in which sound and visibility were modeled in this analysis, the association between higher noise levels and higher annoyance could have been driven entirely by those who could see a wind turbine, while there could still have been no association between wind turbine noise level and annoyance among those who could not see a wind turbine. Thus, this study has to be considered inconclusive with respect to an association between wind turbine sound level and annoyance *independent of* the effect of seeing a wind turbine (and vice versa).

The Dutch study has the limitation of being cross sectional as were the Swedish studies, and the non-response in the Dutch study was much larger than in the Swedish studies. The results of the limited assessment of a subset of non-responders mitigate somewhat against the concerns raised by the low response rate, but not completely.

3.3.c New Zealand Study

The New Zealand study recruited participants from what the authors refer to as two demographically matched neighborhoods (an exposed group living near wind turbines and a control group living far from turbines), although supporting data for this are not presented. The area with the turbines is described as being characterized by hilly terrain, with long ridges running 250–450 m above sea level, on which 66 125 m high wind turbines are positioned. The power of the turbines is not provided. For the exposed group, participants were drawn from those 18 years and older living in 56 houses located within 2 km of a wind turbine, and for the control group participants were drawn from those 18 years and older living in 250 houses located at least 8 km from the wind turbines. It is unclear how many participants per household were recruited, but the final study sample included 39 people in the exposed group and 158 in the control group. Response rates of 34% for the exposed group and 32% for the control group are given. The outcome assessed was response to the abbreviated version of the WHO's quality of life (QOL)-BREF (WHOQOL-BREF)—a health-related QOL questionnaire. These questions were embedded within a larger questionnaire with various facets designed to mask the focus on wind turbines. Although there were no statistically significant demographic differences between the two groups, 43.6% of those in the exposed group had a university education while only 34.2% in the control group did.

The exposed group was found to have significantly worse physical QOL (in particular the sleep and energy level items of this scale) and worse environmental QOL (in particular ratings of how healthy the environment is and satisfaction with the conditions of their living space). The groups did not differ in scores on the social or psychological scales. The mean ratings for an overall QOL item was significantly lower in the exposed group. All of these analyses were adjusted for length of residence, but for no other variables.

As with the other studies discussed, this study has the limitation of being cross sectional. As with the Dutch study, the response rate in the present study is rather low, and unfortunately, there are no data in the New Zealand study on non-participants. This raises concern that self-selection into the study could differ by important factors in some way between the two groups. The difference seen in education level between the groups exacerbates this concern. It is also unclear whether appropriate statistical analysis methods were used given that there may have been multiple respondents from the same household, which is not stated but would have needed to have been accounted for in the analysis. The lack of control for other variables that may be related to reporting of QOL is also a limitation. In this regard it is important to note that a lack of a statistically significant difference in factors between groups does not rule out the possibility of those factors potentially accounting for some of the difference in outcome scores between groups, particularly when the sample size is small like in this study. Whether participants could see wind turbines was not assessed, but it is likely that most if not all in the exposed group could and most if not all in the control group could not, given their locations. Given the findings in the

Swedish and Dutch studies, this means that even if the difference in QOL scores seen are due to wind turbines, it is possible that it is driven by seeing the turbines rather than sound from the turbines. Overall, the level of evidence from this study for a causal association between wind turbines and reported QOL is limited.

3.3.d Additional Non-Peer Reviewed Documents

Papers that appear in the peer-reviewed literature have by definition undergone a level of review external to the study team by not only the editors of the journal, but also two to three (usually) scientists familiar with the field of the study and the methodology used. These hurdles provide an opportunity to identify problems with the paper—from methodology to interpretation of the results—and either provide the opportunity to address problems or reject the paper if the problems are considered fatal to the interpretation of the results. Non-peer reviewed literature is not subject to this external review scrutiny. This does not mean that all peer-reviewed literature is of high quality nor that non-peered reviewed literature is necessarily inferior to peer-reviewed literature, but it does mean that non-peered reviewed literature does not need to undergo any review process to appear. Indeed, at times studies appear in non-peer reviewed outlets precisely because they did not meet the bar of quality necessary to appear in the peer-reviewed literature. Thus, non-peer reviewed literature needs to be scrutinized with this in mind. Four such non-peer-reviewed reports are described below. In addition to those four, a few early reports of annoyance from wind turbines generally found a weak relationship between annoyance and the equivalent A-weighted SPL, although those studies were mainly based on studies of smaller turbines of less than 500 kW (T. H. Pedersen & Nielsen, 1994; Rand & Clarke, 1990; Wolsink et al., 1993).

Project WINDFARMperception: Visual and acoustic impact of wind turbine farms on residents (van den Berg et al., 2008). This report describes the study upon which the Dutch paper summarized above (E. Pedersen et al., 2009) is based. The characteristics of the wind turbines are thus as described above. In addition to the data that appeared in the peer-reviewed literature, this report describes analyses of additional data that was collected. These additional data relate to health effects and turbine noise exposure. The questionnaire assessed stress levels with the General Health Questionnaire (GHQ), a validated scale that has been widely used in such studies and which assesses symptoms felt over the past several weeks. In models adjusted for age, economic benefit from the turbines, and sex, there was no association between sound levels and stress. In contrast, there was a significant association between sound levels and interrupted sleep (at least once a month), even when further adjusting for background noise levels. This was most obvious at turbine noise levels >45 dB(A), but there appeared to be an increasing trend in occurrence of interrupted sleep with increasing noise categories even across the lower noise categories. This study also asked participants about chronic health conditions including diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, and migraine. Although no associations were seen between wind turbine noise and these outcomes in adjusted analyses, the chronic nature of these outcomes and the lack of data on timing of onset with respect to when the wind turbines were introduced make interpreting these negative findings difficult.

Report to the commission related to Moturimu wind farm, New Zealand (Phipps, 2007). This report to a commission in New Zealand related to the Moturimu wind farm describes a survey conducted by Robyn Phipps to investigate the visual and acoustical effects experienced by residents living at least 2 km from existing wind farms in the Manawatu and Tararua regions of New Zealand. Most respondents were within 3 km, although a few lived further away, as far as 15 km. The characteristics and number of wind turbines was not provided. Although this work does not appear to have come out in the peer-reviewed literature, reasonable details about the methodology are provided.

Roughly 1,100 surveys were delivered to postal addresses and 614 (56%) were returned. Participants were asked to rate on a scale of 1–5 their agreement with different statements related to their perceptions of the wind turbines. When these questions dealt with visual issues, they were framed both positively and negatively (e.g., “I think the turbines spoil the view,” and “I think the turbines are quite attractive”). This apparently was not the case with other questions (e.g., “Watching the turbines can create an unpleasant physical sensation in my body”).

Overall, 9% of respondents endorsed being “affected” by the flicker of the wind turbines; 15% were sufficiently bothered by the visual and noise effects of the turbines to consider complaining, and 10% actually had complained. While 56% is a relatively good response rate for a mailed survey, the reasons for non-response of nearly half of potential participants must be considered. It is possible that non-respondents did not care enough about the effects of the wind turbines to bother responding, which presumably would lower the overall percentages that were “affected” by the turbines. On the other hand, it is not clear how long the turbines were in operation prior to the survey, and it is conceivable that some more affected people may have moved out of the area before the time of the survey.

A further drawback to the reported survey was that there was not a determination of how the percentage of "affected" respondents related to distance from the turbines, the ability to see the turbines, or noise levels experienced from the turbines. The report cites a lot of literature on noise and health effects, and while such effects have been reported in the literature, they are almost uniformly at sound levels above what is usually found for people living near turbines (and most certainly higher than those usually reported for people living more than 2 km from a turbine). A WHO report provides a good review of this literature (WHO, 2009). The lowest threshold levels for seeing any effect are about 35 dB(A) (maximum per event or L_{Amax}) for some physiological sleep responses (e.g., EEG, or duration of sleep stages), but these thresholds are for levels inside the house near the sleeper, which will be much lower than what is experienced outside the house. The lowest threshold level for complaints of well-being were estimated at 35 dB(A) as a yearly average outside the house at night ($L_{night,\ outside}$). But for health outcomes the thresholds for any effect are much higher, for example 50 dB(A) ($L_{night,\ outside}$) for hypertension or myocardial infarction.

"Wind Turbine Syndrome" (Pierpont, 2009): This book describes several people who suffer health symptoms that they attribute to wind turbines. Such descriptions can be informative in describing phenomena and raising suggestions for possible follow-up with more rigorous study designs, but generally are not considered evidence for causality. In this particular case, though, there are elements that go beyond the most basic symptom descriptions and so warrant consideration as a study. But limitations to the design employed make it impossible for this work to contribute any evidence to the question of whether there is a causal association between wind turbine exposure and health effects. Given this, the very term "Wind Turbine Syndrome" is misleading as it implies a causal role for wind turbines in the described health symptoms.

The book describes health symptoms experienced among 38 people from 10 different families who lived near wind turbines and subsequently either moved away from the turbines or spent significant periods of time away. The participants ranged in age from less than 1 to 75 years old, with 13 (34%) younger than 16 years and 17 (45%) younger than 22. The participants were queried about their health symptoms before exposure to turbines (presumably before the turbines were operational), during exposure to turbines, and after moving away. There is an impressive detailed description of the extent and severity of health symptoms experienced by this group, with a core group of symptoms centered around vibratory responses and termed Visceral Vibratory Vestibular Disturbance (VVVD) by Pierpont. While these symptoms for the most part are attributed to exposure to the wind turbines by the participants—either because they appeared once the turbines were operational or because they seemed to diminish after going away from the turbines—the way in which these participants were recruited makes it impossible to draw any conclusions about attributing causality to the turbines.

The most critical problem with respect to inferring causality from Pierpont's findings lies in how the families were identified for participation. To be included in the study, among other criteria, at least one family member had to have severe symptoms *and* reside near a recently erected wind turbine. In epidemiological terms this is selecting participants based on both exposure and outcome, which guarantees a biased (non-causal) association between wind turbines and symptoms. While it could be argued that other family members may not have had severe symptoms—and so would not be selected based on outcome—it is hard to consider other family members as truly independent observations, as their reporting of symptoms, or indeed their experiencing of symptoms, could be influenced by the more severely affected family member. This is particularly so when the symptoms are in the realm of anxiety, sleep disturbance, memory, and concentration; and the severely affected family members are reporting increased irritability, anger, and shouting.

Although not always, several of the participants reported an improvement of symptoms after moving away from the wind turbines. While this is suggestive and should not be discounted as something to explore further, the highly selective nature of the interviewed group as a whole makes the evidence for causality from these data *per se* weak. There are also many factors that change when moving, making it difficult to attribute changes to any specific difference with certainty. Additional factors that contribute to the inability to infer causality from these data include the small sample size, lack of detail on the larger population that could have been considered for inclusion in the study, and lack of detail on precisely how the actual participants were recruited. In addition, while the clinical history was extensive, the symptom data were all self-reported. Another complication is that there are no precise data on distance to turbines, and noise levels or infrasound vibration levels at the participants' homes.

“Adverse health effects of industrial wind turbines: a preliminary report” (Nissenbaum et al., 2011): This report describes a study involving questionnaire assessment of mental and physical health (SF-36), sleep disturbance (Pittsburgh Sleep Quality Index), and sleepiness (Epworth Sleepiness Scale) among residents near one of two wind farms in Maine (Vinalhaven & Mars Hill). The Mars Hill site is a linear arrangement of 28 General Electric 1.5 MW turbines, sited on a ridgeline. The Vinalhaven site is a cluster of three similar turbines, sited on a flat, tree-covered island. All residents within 1.5 km of one of the turbines were identified, and all those older than 18 years and non-demented were considered eligible for the study. A set of households from an area of similar socioeconomic makeup but 3–7 km from wind turbines were also recruited. The recruitment process involved house-to-house visits up to three times to recruit participants. Among those within at most 1.5 km from the nearest turbine, 65 adults were identified and 38 (58%; 22 male, 16 female) participated from 23 unique households. Among those 3-7 km from the nearest turbine, houses were visited until a similar number of participants were recruited. This process successfully recruited 41 adults (18 male, 23 female) from 33 unique households. No information was given on the number of homes or people approached so the participation rate cannot be determined.

Analyses adjusted for age, sex, and site (the two different wind farms) found that those living within 1.5 km of a wind turbine had worse sleep quality and mental health scores and higher ratings of sleepiness than those living 3–7 km from a turbine. Physical health scores did not differ between the groups. Similar associations were found when distance to the nearest turbine was analyzed as a continuous variable.

This study is somewhat limited by its size—much smaller than the Swedish or Dutch studies described above—but nonetheless suggests relevant potential health impacts of living near wind turbines. There are, however, critical details left out of the report that make it difficult to fully assess the strength of this evidence. In particular, critical details of the group living 3–7 km from wind turbines is left out. It is stated that the area is of similar socioeconomic makeup, and while this may be the case, no data to back this up are presented—either on an area level or on an individual participant level. In addition, while the selection process for these participants is described as random, the process of recruiting these participants by going home to home until a certain number of participants are reached is not random. Given this, details of how homes were identified, how many homes/people were approached, and differences between those who did and did not participate are important to know. Without this, attributing any of the observed associations to the wind turbines (either noise from them or the sight of them) is premature.

3.3.e Summary of Epidemiological Data

There is only a limited literature of epidemiological studies on health effects of wind turbines. Furthermore, existing studies are limited by their cross sectional design, self-reported symptoms, limited ability to control for other factors, and to varying degrees of non-response rates. The study that accounted most extensively for other factors that could affect reported symptoms had a very low response rate (E. Pedersen et al., 2009; van den Berg, et al., 2008).

All four peer-reviewed papers discussed above suggested an association between increasing sound levels from wind turbines and increasing annoyance. Such an association was also suggested by two of the non-peer reviewed reports that met at least basic criteria to be considered studies. The only two papers to consider the influence of seeing a wind turbine (each one of the peer-reviewed papers) both found a strong association between seeing a turbine and annoyance. Furthermore, in the studies with available data, the influence of either sound from a turbine or seeing a turbine was reduced—if not eliminated, as was the case for sound in one study—when both of these factors were considered together. However, this precise relation cannot be disentangled from the existing literature because the published analyses do not properly account for both seeing and hearing wind turbines given the relation between these two that the data seem to suggest. Specifically, the possibility that there may be an association between either of those factors and annoyance, but possibly only for those who both see and hear sound from a turbine, and not for those who either do not hear sound from or do not see a turbine. Furthermore, in the one study to consider whether individuals benefit economically from the turbines in question, there appeared to be virtually no annoyance regardless of whether those people could see or hear a turbine. Even if one considers the data just for those who could see a wind turbine and did not benefit economically from the turbines, defining at what noise levels the percentage of those annoyed becomes more dramatic is difficult. Higher percentages of annoyance did appear to be more consistent above 40 dB(A). Roughly 27% were annoyed (at least 4 on a 1–5 point scale of annoyance; 5 being the worst), while roughly 18% were very annoyed (5 on a 1–5 scale). The equivalent levels of annoyed and very annoyed for 35–40 dB(A) were roughly 15% and 6%, respectively. These percentages, however, should be considered upper bounds for a specific relation with noise levels because, with respect to estimating direct effects of noise, they are likely inflated as a result of both selective participation in the studies and the fact that the percentages do not take into account the effect of seeing a turbine.

Thus, in considering simply exposure to wind turbines in general, while all seem to suggest an association with annoyance, because even the peer-reviewed papers have weaknesses, including the cross sectional designs and sometimes quite low response rates, **the Panel concludes that there is limited evidence suggesting an association between exposure to wind turbines and annoyance**. However, only two of the studies considered both seeing and hearing wind turbines, and even in these the possible contributions of seeing and hearing a wind turbine were not properly disentangled. Therefore, **the Panel concludes that there is insufficient evidence to determine whether there is an association between noise from wind turbines and annoyance independent from the effects of seeing a wind turbine and vice versa**. Even these conclusions must be considered in light of the possibility suggested from one of the peer-reviewed studies that there is extremely low annoyance—regardless of seeing or hearing sound from a wind turbine—among people who benefit economically from the turbines.

There was also the suggestion that poorer sleep was related to wind turbine noise levels. While it intuitively makes sense that more noise would lead to more sleep disruption, there is limited data to inform whether this is occurring at the noise levels produced from wind turbines. An association was indicated in the New Zealand study, suggested without presenting details in one of the Swedish studies, and found in two non-peer-reviewed studies. Therefore, **the Panel concludes that there is limited evidence suggesting an association between noise from wind turbines and sleep disruption and that further study would quantify precise sound levels from wind turbines that disrupt sleep**.

The strongest epidemiological study to examine the association between noise and psychological health suggests there is not an association between noise from wind turbines and measures of psychological distress or mental health problems. There were two smaller, weaker, studies: one did note an association, one did not. Therefore, **the Panel concludes the weight of the evidence suggests no association between noise from wind turbines and measures of psychological distress or mental health problems.**

One Swedish study apparently collected data on headache, undue tiredness, pain and stiffness in the back, neck, or shoulders, or feeling tensed/stressed and irritable, but did not report on analyses of these data. The Dutch study found no association between noise from wind turbines and diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, and migraine, although this was not reported in the peer-reviewed literature. Therefore, **the Panel concludes that none of the limited epidemiological evidence reviewed suggests an association between noise from wind turbines and pain and stiffness, diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, and headache/migraine.**

These conclusions align with those presented in the peer-reviewed article by Knopper and Ollson (2011). They write "Conclusions of the peer reviewed literature differ in some ways from those in the popular literature. In peer reviewed studies, wind turbine annoyance has been statistically associated with wind turbine noise, but found to be more strongly related to visual impact, attitude to wind turbines and sensitivity to noise. … it is acknowledged that noise from wind turbines can be annoying to some and associated with some reported health effects (e.g., sleep disturbance), especially when found at sound pressure levels greater than 40 db(A)."

3.4 Exposures from Wind Turbines: Noise, Vibration, Shadow Flicker, and Ice Throw

In addition to the human epidemiologic study literature on exposure to wind turbines and health effects described in the section above, the Panel assessed literature that could shed light on specific exposures resulting from wind turbines and possible health effects. The exposures covered here include noise and vibration, shadow flicker, and ice throw. Each of these exposures is addressed separately in light of their documented and potential health effects. When health effects are described in the popular media, these claims are discussed.

3.4.a Potential Health Effects Associated with Noise and Vibration

The epidemiologic studies discussed above point to noise from wind turbines as a source of annoyance. The studies also noted that some respondents note sleep disruption due to the turbine noise. In this section, the characteristics of audible and inaudible noise from turbines are discussed in light of our understanding of their impacts on human health.

It is clear that when sound levels get too high, the sound can cause hearing loss (Concha-Barrientos et al., 2004). These sound levels, however, are outside the range of what one would experience from a wind turbine. There is evidence that levels of audible noise below levels that cause hearing loss can have a variety of health effects or indicators. Detail about the evidence for such health effects have been well summarized in a WHO report that came to several relevant conclusions (WHO, 2009). First, there is sufficient evidence for biological effects of noise during sleep: increase in heart rate, arousals, sleep stage changes and awakening; second, there is limited evidence that noise at night causes hormone level changes and clinical conditions such as cardiovascular illness, depression, and other mental illness. What the WHO report also details is observable noise threshold levels for these potential effects. For such health effects, where data are sufficient to estimate a threshold level, that level is never below 40 dB(A)—as a yearly average—for noise outside (ambient noise) at night—and these estimates take into account sleeping with windows slightly open.

One difficulty with the WHO threshold estimate is that a yearly average can mask the particular quality of turbine noise that leads survey respondents to note annoyance or sleep disruption. For instance, the pulsatile nature of wind turbine noise has been shown to lead to respondents claiming annoyance at a lower averaged sound level than for road noise (E. Pederson, 2004). Yearly averaging of sound eliminates (or smooths) the fluctuations in the sound and ignores differences between day and night levels. Regulations may or may not take this into account.

Health conditions caused by intense vibration are documented in the literature. These are the types of exposures that result from jackhammers, vibrating hand tools, pneumatic tools, etc. In these cases, the vibration is called arm-body or whole-body vibration. Vibration can cause changes in tendons, muscles, bones and joints, and can affect the nervous system. Collectively, these effects are known as Hand-Arm Vibration Syndrome (HAVS). Guidelines and interventions are intended to protect workers from these vibration-induced effects (reviewed by European Agency for Safety and Health at Work, 2008; (NIOSH 1989). OSHA does not have standards concerning vibration exposure. The American Conference of Governmental Industrial Hygienists (ACGIH) has developed Threshold Limit Values (TLVs) for vibration exposure to hand-held tools. The exposure limits are given as frequency-weighted acceleration (NIOSH, 1989).

3.4.a.i Impact of Noise from Wind Turbines on Sleep

The epidemiological studies indicate that noise and/or vibration from wind turbines has been noted as causing sleep disruption. In this section sleep and sleep disruption are discussed. In addition, suggestions are provided for more definitively evaluating the impact of wind turbines on sleep.

All sounds have the potential to disrupt sleep. Since wind turbines produce sounds, they might cause sleep disruption. A very loud wind turbine at close distance would likely disrupt sleep, particularly in vulnerable populations (such as those with insomnia or mood disorders, aging populations, or “light sleepers”), while a relatively quiet wind turbine would not be expected to disrupt even the lightest of sleepers, particularly if it were placed at considerable distance.

There is insufficient evidence to provide very specific information about how likely particular sound-pressure thresholds of wind turbines are at disrupting sleep. Physiologic studies of noises from wind turbines introduced to sleeping people would provide these specific levels. Borrowing existing data (e.g., Basner, 2011) and guidelines (e.g., WHO) about noises at night, beyond wind turbines, might help provide reasonable judgment about noise limits at night. But it would be optimal to have specific data about the particular influence that wind turbines have on sleep.

In this section we introduce broad concepts about sleep, the interaction of sleep and noises, and the potential for wind turbines to cause that disruption.

Sleep

Sleep is a naturally occurring state of altered consciousness and reduced physical activity that interacts with all aspects of our physiology and contributes daily to our health and well-being.

Measurements of sleep in people are typically performed with recordings that include electroencephalography (EEG). This can be performed in a laboratory or home, and for clinical or experimental purposes. Other physiological parameters are also commonly measured, including muscle movements, lung, and heart function.

While the precise amount of sleep that a person requires is not known, and likely varies across different people and different ages, there are numerous consequences of reduced sleep (i.e., sleep deprivation).

Deficiencies of sleep can take numerous forms, including the inability to initiate sleep; the inability to maintain sleep; abnormal composition of sleep itself, such as too little deep sleep (sometimes called slow-wave sleep, or stage N3); or frequent brief disruptions of sleep, called arousals. Sources of sleep deprivation can be voluntary (desirable or undesirable) or involuntary. Voluntary sources include staying awake late at night or awakening early. These can be for work or school, or while engaging in some personal activities during normal sleep times. Sleep deprivation can also be caused by myriad involuntary and undesired problems (including those internal to the body such as pain, anxiety, mood disorders) and frequent need to urinate, or by numerous sleep disorders (including insomnia, sleep apnea, circadian disorders, parasomnias, sleep-related movement disorders, etc), or simply by the lightening of sleep depth in normal aging. Finally, sleep deprivation can be caused by numerous external factors, such as noises or other sensory information in the sleeper's environment.

Sleep is conventionally categorized into rapid eye movement (REM) and non-REM sleep. Within the non-REM sleep are several stages of sleep ranging from light sleep to deep sleep. Beyond these traditional sleep categories, the EEG signal can be analyzed in a more detailed and sophisticated way, including looking at the frequency composition of the signals. This is important in sleep, as we now know that certain signatures in the brain waves (i.e., EEG) disclose information about who is vulnerable to noise-induced sleep disruption, and what moments within sleep are most vulnerable (Dang-Vu et al., 2010; McKinney et al., 2011).

Insomnia can be characterized by a person having difficulty falling asleep or staying asleep that is not better explained by another condition (such as pain or another sleep disorder) (see ICSD, 2nd Edition for details of the diagnostic criteria for insomnia). Approximately 25% of the general population experience occasional sleep deprivation or insomnia. Sleep deprivation is defined by reduced quantity or quality of sleep, and it can result in excessive daytime sleepiness as well as problems including those associated with mood and cognitive function (Roth et al., 2001; Rogers, 2007; Walker, 2008). As might be expected, the severity of the sleep deprivation has an impact on the level of cognitive functioning, and real-life consequences can include driving accidents, impulsive behaviors, errors in attention, and mood problems (Rogers, 2007; Killgore, 2010). Loss of sleep appears to be cumulative, meaning it adds up night after night. This can result in subtle impairments in reaction times, decision-making ability, attentional vigilance, and integration of information that is sometimes only apparent to the sleep-deprived individual after an accident or error occurs, and sometimes not perceived by the sleep-deprived person at all (Rogers, 2007; van Dongen 2003).

Sleep and Wind Turbines

Given the effects of sleep deprivation on health and well-being, including problems with mood and cognition, it is possible that cognitive and mood complaints and other medical or psychological issues associated with sleep loss can stem from living in immediate proximity to wind turbines, if the turbines disrupt sleep. Existing data, however, on the relationship between wind turbines and sleep are inadequate. Numerous factors determine whether a sound disrupts sleep. Broadly speaking, they are derived from factors about the sleeper and factors about the sound.

Case reports of subjective complaints about sleep, particularly those not critically and objectively appraised in the normal scientific manner, are the lowest level of evidence, not simply because they lack any objective measurements, but also because they lack the level of scrutiny considered satisfactory for making even crude claims about cause and effect. For instance, consider the case of a person who sleeps poorly at home (near a wind turbine), and sleeps better when on vacation (away from a wind turbine). One might conclude from this case that wind turbines cause sleep disruption for this person, and even generalize that information to other people. But there are numerous factors that might make it more likely that a person can sleep well on vacation, having nothing to do with the wind turbine. Furthermore, given the enormous prevalence of sleep disorders, such as insomnia, and the potentially larger prevalence of disorders that impinge on sleep, such as depression, it is crucial that these factors be taken into consideration when weighing the evidence pointing to a causal effect of wind turbines on sleep disruption for the general population. It is also important to obtain objective measurements of sleep, in addition to subjective complaints.

Subjective reports of sleeping well or sleeping poorly can be misleading or even inaccurate. People can underestimate or overestimate the quality of their sleep. Future studies should examine the acoustic properties of wind turbines when assessing the elements that might disrupt sleep. There are unique properties of the noises wind turbines make, and there are some acoustic properties in common with other noises (such as trucks or trains or airplanes). It is important to make these distinctions when assessing the effects of wind turbines on noise, by using data from other noises. Without this physiologic, objective information, the effects of wind turbines on sleep might be over- or underestimated.

It should be noted that not all sounds impair the ability to fall asleep or maintain sleep. To the contrary, people commonly use sound-masking techniques by introducing sounds in the environment that hinder the perception of undesirable noises. Colloquially, this is sometimes called “white noise,” and there are certain key acoustic properties to these kinds of sounds that make them more effective than other sounds. Different noises can affect people differently. The emotional valence that is ascribed by an individual to a particular sound can have a major influence on the ability to initiate or maintain sleep. Certain aspects of sounds are particularly alerting and therefore would be more likely to disrupt sleep at lower sound pressure levels. But among those that are not, there is a wide range of responses to these sounds, depending partly on the emotional valence ascribed to them. A noise, for instance, that is associated with a distressing object, is more likely to impede sleep onset.

Finally, characteristics of sleep physiology change across a given night of sleep—and across the life cycle of a person—and are different for different people, including the effects of noise on sleep (e.g., Dang-Vu et al., 2010; McKinney et al., 2011). And some people might initially have difficulty with noises at night, but habituate to them with repeated exposure (Basner, 2011).

In summary, **sleep is a complex biological state, important for health and well-being across a wide range of physiologic functions. To date, no study has adequately examined the influence of wind turbines on sleep.**

Future directions: The precise effects of noise-induced sleep disruption from wind turbines may benefit from further study that examines sound-pressure levels near the sleeper, while simultaneously measuring sleep physiology to determine responses of sleep to a variety of levels of noise produced by wind turbines. The purpose would be to understand the precise sound-pressure levels that are least likely to disturb sleep. It would also be helpful to examine whether sleepers might habituate to these noises, making the impact of a given sound less and less over time. Finally, it would be helpful to study these effects in susceptible populations, including those with insomnia or mood disorders or in aging populations, in addition to the general population.

Summary of Sleep Data

In summary, sleep is a complex biological state, important for health and well-being across a wide range of physiologic functions. **To date, no study has adequately examined the influence of wind turbines and their effects on sleep.**

3.4.b Shadow Flicker Considerations and Potential Health Effects

Shadow flicker is caused when changes in light intensity occur from rotating wind turbine blades that cast shadows (see Appendix B for more details on the physics of the phenomenon.) These shadows move on the ground and on buildings and structures and vary in terms of frequency rate and intensity. Shadow flicker is reported to be less of a problem in the United States than in Northern Europe due to higher latitudes and lower sun angles in Europe. Nonetheless, it can still be a considerable nuisance to individuals exposed to shadow flicker for considerable amounts of time per day or year in the United States as well. Shadow flicker can vary significantly by wind speed and duration, geographic location of the sunlight, and the distance from the turbine blades to any relevant structures or buildings. In general, shadow flicker branches out from the wind turbine in a declining butterfly wing characteristic geographic area with higher amounts of flicker being closer to the turbine and less flicker in the outer parts of the geographic area (New England Wind Energy Education Project (NEWEEP), 2011; Smedley et al., 2010). Shadow flicker is present up until approximately 1400 m, but the strongest flicker is up to 400 m from the turbine when it occurs (NEWEEP, 2011). In addition, shadow flicker usually occurs in the morning and evening close to sunrise and sunset when shadows are the longest. Furthermore, shadow flicker can fluctuate in different seasons of the year depending on the geographic location of the turbine such that some sites will only report flicker during the winter months while others will report it during summer months. Other factors that determine shadow flicker rates and intensity include objects in the landscape (i.e., trees and other existing shadows) and weather patterns. For instance, there is no shadow flicker on cloudy days without sun as compared with sunny days. Also, shadow flicker speed (shadows passing per second) increases with the rotor speed (NRC, 2007). In addition, when several turbines are located relatively close to one another there can be combined flicker from the different blades of the different turbines and conversely, if situated on different geographic areas around structures, shadow flicker can occur at different times of the day at the same site from the different turbines so pre-planning of siting location is very important (Harding et al., 2008). General consensus in Germany resulted in the guidance of 30 hours per year and 30 minutes per day (based on astronomical, clear sky calculations) as acceptable limits for shadow flicker from wind turbines (NRC, 2007). This is similar to the Denmark guidance of 10 hours per year based on actual conditions.

3.4.b.i Potential Health Effects of Flicker

Because some individuals are predisposed to have seizures when exposed to certain types of flashing lights, there has been concern that wind turbines had the potential to cause seizures in these vulnerable individuals. In fact, seizures caused by visual or photic stimuli are typically observed in people with certain types of epilepsy (Guerrini & Genton, 2004), particularly generalized epilepsy. While it is not precisely known how many people have photosensitivity that causes seizures, it appears to be approximately 5% of people with epilepsy, amounting to about 100,000 people in the United States. And many of these people will already be treated with antiepileptic medications thus reducing this risk further.

Fortunately, not all flashing light will elicit a seizure, even in untreated people with known photosensitivity. There are several key factors that likely need to simultaneously occur in order for the stimulus to induce a seizure, even among the fraction of people with photosensitive seizures. The frequency of the stimulus is important as is the stimulus area and pattern (See below) (http://www.epilepsyfoundation.org/aboutepilepsy/seizures/photosensitivity/gerba.cfm).

Frequencies above 10 Hz are more likely to cause epileptic seizures in vulnerable individuals, and seizures caused by photic stimulation are generally produced at frequencies ranging from greater than 5 Hz. However, shadow flicker frequencies from wind turbines are related to the rotor frequency and this usually results in 0.3–1.0 Hz, which is outside of the range of seizure thresholds according to the National Resource Council and the Epilepsy Foundation (NRC, 2007). In fact, studies performed by Harding et al. (2008) initially concluded that because light flicker can affect the entire retina, and even if the eyes are closed that intermittent light can get in the retina, suggested that 4 km would be a safe distance to avoid seizure risk based on shadow flicker (Harding et al., 2008). However, a follow-up analysis considering different meteorological conditions and shadow flicker rates concluded that there appeared to be no risk for seizures unless a vulnerable individual was closer than 1.2 times the total turbine height on land and 2.8 times the total turbine height in the water, which could potentially result in frequencies of greater than 5 Hz (Smedley et al., 2010).

Although some individuals have complained of additional health complaints including migraines, nausea, dizziness, or disorientation from shadow flicker, only one government-sponsored study from Germany (Pohl et al., 1999) was identified for review. This German study was performed by the Institute of Psychology, Christian-Albrechts-University Kiel on behalf of the Federal Ministry of Economics and Technology (BMWi) and supported by the Office of Biology, Energy, and Environment of the Federal Ministry for Education and Research (BMBF), and on behalf of the State Environmental Agency of Schleswig. The purpose of this government-sponsored study was to determine whether periodic shadow with a duration of more than 30 minutes created significant stress-related health effects. The shadows were created by a projection system, which simulated the flicker from actual wind turbines.

Two groups of different aged individuals were studied. The first group consisted of 32 students (average age 23 years). The second group included 25 professionals (average age 47 years). Both men and women were included. The subjects were each randomly assigned to one of two experimental groups, so there was a control group and an experimental group. The experimental group was exposed to 60 minutes of simulated flicker. For the control group lighting conditions were the same as in the experimental group, but without periodic shadow. The main part of the study consisted of a series of six test and measurement phases, two before the light was turned on, three each at intervals of 20 minutes while the simulated shadow flickering was taking place, and one more after the flicker light was turned off. Among the variables measured were general performance indicators of stress (arithmetic, visual search tasks) and those of mental and physical well-being, cognitive processing, and stress in the autonomic nervous system (heart rate, blood pressure, skin conductance, and finger temperature). Systematic effects due to the simulated flicker could be detected in comparable ways in both exposure groups studied. Both physical and cognitive effects were found in this exposure scenario for shadow flicker.

It appears clear that shadow flicker can be a significant annoyance or nuisance to some individuals, particularly if they are wind project non-participants (people who do not benefit economically or receive electricity from the turbine) whose land abuts the property where the turbine is located. In addition, flashing (a phenomenon closely related to shadow flicker, but due to the reflection of sunlight – see Appendix B) can be a problem if turbines are sited too close to highways or other roadways. This could cause dangerous conditions for drivers. Accordingly, turbine siting near highways should be planned so as to reduce flashing as much as possible to protect drivers. However, use of low reflective turbine blades is commonly employed to reduce this potential flashing problem. Provisions to avoid many of these potential health and annoyance problems appear to be employed as current practice in many pre-planning sites with the use of computer programs such as WindPro. These programs can accurately determine shadow flicker rates based on input of accurate analysis area, planned turbine location, the turbine design (height, length, hub height, rotor diameter, and blade width), and residence or roadway locations. Many of these computer programs can then create maps indicating the location and incidence of shadow flicker. Such programs may also provide estimates of daily minutes and hours per year of expected shadow flicker that can then be used for wind turbine planning and siting or for mitigation efforts. Several states require these analyses to be performed before any new turbine projects can be implemented.

3.4.b.ii Summary of Impacts of Flicker

Collectively, although shadow flicker can be a considerable nuisance particularly to wind turbine project non-participants, the evidence suggests that there is no risk of seizure from shadow flicker caused by wind turbines. In addition, there is limited evidence primarily from a German government-sponsored study (Pohl et al., 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). There was insufficient documentation to evaluate other than anecdotal reports of additional health effects including migraines or nausea, dizziness or disorientation. There are documented mitigation methods for addressing shadow flicker from wind turbines and these methods are presented in Appendix B.

3.4.c Ice Throw and its Potential Health Effects

Under certain weather conditions ice may form on the surface of wind turbine blades. Normally, wind turbines intended for use in locations where ice may form are designed to shut down when there is a significant amount of ice on the blades. The means to prevent operation when ice is present may include ice sensor and vibration sensors. Ice sensors are used on most wind turbines in cold climates. Vibration sensors are used on nearly all wind turbines. They would cause the turbine to shut down, for example, if ice buildup on the blades resulted in an imbalance of the rotor and hence detectable vibrations in the structure.

Ice built up on blades normally falls off while the turbine is stationary. If that occurs during high winds, the ice could be blown by the wind some distance from the tower. In addition, it is conceivable that ice could be thrown from a moving wind turbine blade under some circumstances, although that would most likely occur only during startup (while the rotational speed is still relatively low) or as a result of the failure of the control system. It is therefore worth considering the maximum plausible distance that a piece of ice could land from the turbine under two “worst case” circumstances: 1) ice falls from a stopped turbine during very high winds, and 2) ice is suddenly released from a blade when the rotor is rotating at its normal operating speed.

Ice is a physical hazard, that depending on the mass, velocity, and the angle of throw can result in a wide range of effects to humans: alarm and surprise to abrasions, organ damage, concussions, and perhaps death. Avoidance of ice throw is critical. More detail on ice throw and options for mitigation are presented in Appendix C.

3.5 Effects of Noise and Vibration in Animal Models

Domestic animals such as cats and dogs can serve as sentinels of problematic environmental conditions. The Panel searched for literature that might point to non-laboratory animal studies or well-documented cases of animals impacted by wind turbines. Anecdotal reports in the press of goat deaths (UK), premature births and adverse effects in cows (Japan, US) provide circumstantial evidence, but lack specifics regarding background rates of illness or extent of impact.

Laboratory-based animal models are often used to predict and to develop mechanistic explanations of the causes of disease by external factors, such as noise or chemicals in humans. In the absence of robust epidemiological data, animal models can provide clues to complex biological responses. However, the limitations of relying on animal models are well documented, particularly for endpoints that involve the brain. The benefits of using an animal model include ease of experimental manipulation such as multiple exposures, typically well-controlled experimental conditions, and genetically identical groups of animals.

Evaluation of biological plausibility for the multitude of reported health effects of wind turbines requires a suitable animal model documented with data that demonstrate cause and effect. Review of this literature began with a PubMed and ToxNet search for “wind turbine” or “wind turbines”; or “infrasound” or “low frequency noise”; and “animal” or “mammal” to identify peer-reviewed studies in which laboratory animals were exposed to noise or vibration intended to mimic that of wind turbines. Titles and abstracts of identified papers were read to make a first pass determination of whether the paper was a study on effects in mammals or might contain relevant references to other relevant studies. The searches yielded several studies, many of which were not peer-reviewed, were not whole-animal mammalian or were not experimental, but were reviews in which animal studies were mentioned or experiments conducted in dissected cochlea. The literature review yielded eight peer-reviewed studies, all relying on the laboratory rat as the model. The studies fall into two groups—those conducted in the 1970's and early 1980's and those conducted in 2007–2010. The most recent studies are conducted in China and are funded by the National Natural Science Foundation of China. Table AG.1 (in Appendix G) provides a summary of the studies.

There is no general agreement about the specific biological activity of infrasound on rodents, although at high doses it appears to negatively affect the cardiovascular, brain, and respiratory systems (Sienkiewicz, 2007). Early studies lacked the ability to document the doses of infrasound given the rats, did not report general pathologies associated with the exposures and lacked suitable controls. Since then, researchers have focused on the brain and cardiac systems as sensitive targets of infrasound. Experimental conditions in these studies lack a documented rationale for the selection and the use of infrasound of 5-15 Hz at 130 dB. While this appears to be standard practice, the relevance of these frequencies and pressures is unclear—both to the rat and more importantly to the human. The exposures are acute—short-term, high dose. Researchers do not document rat behaviors (including startle responses), pathologies, frank toxicities, and outcomes due to these exposures. Therefore, interpretation of all of the animal model data for infrasound outcomes must be with the lens of any high-dose, short-term exposure in toxicology, specifically questioning whether the observations are readily translatable to low-dose, chronic exposures.

Pei et al., (2007 and 2009) examine changes in cardiac ultrastructure and function in adult male Sprague-Dawley rats exposed to 5 Hz at 130 dB for 2 hours for 1, 7, or 14 successive days. Cardiomyocytes were enzymatically isolated from the adult left ventricular hearts after sacrifice. Whole cell patch-clamp techniques were employed to measure whole cell L-Type Ca^{2+} currents. The objective of these studies was to determine whether there was a cumulative effect of insult as measured by influx of calcium into cardiomyocytes. After infrasound exposure, rats in the 7– and 14–day exposure groups demonstrated statistically significant changes in intracellular Ca^{2+} homeostasis in cardiomyocytes as demonstrated by electrochemical stimulation of the cells, molecular identification of specific heart-protein levels, and calcium transport measurements.

Several studies examine the effects of infrasound on behavioral performance in rats. The first of these studies was conducted under primitive acoustic conditions compared with those of today (Petounis et al., 1977). In this study the researchers examined the behavior of adult female rats (undisclosed strain) exposed to increasing infrasound (2 Hz, 104 dB; 7 Hz, 122 dB; and 16

Hz, 124 dB) for increasing time (5-minute increments for up to 120 minutes). Decreased activity levels (sleeping more) and exploratory behavior were documented as dose and duration of exposure increased. The authors fail to mention that frank toxicity including pain is associated with these behaviors, raising the question of relevance of high dose exposures. In response to this and similar studies that identify increase in sleep, increase in avoidance behaviors and suppression of locomotor activity, Spyraki et al., (1977) hypothesized that these responses are mediated by norepinephrine levels in the brain and as such, exposed adult male Wistar rats to increasing doses of infrasound for one hour. Using homogenized brain tissue, norepinephrine concentrations were measured using fluorometric methods. Researchers demonstrated a dose-dependent decrease in norepinephrine levels in brain tissue from infrasound-treated rats, beginning at a dose of 7 Hz and 122 dB for one hour. No observations of frank toxicity were recorded. Liu et al., (2010) hypothesized that since infrasound could affect the brain, it potentially could increase cell proliferation (neurogenesis) in the dentate gyrus of the rat hippocampus, specifically a region that continues to generate new neurons in the adult male Sprague-Dawley rat. Using a slightly longer exposure period of 2 hours/day for 7 days at 16 Hz and 130 dB, the data suggest that infrasound exposure inhibits cell proliferation in the dentate gyrus, yet has no affect on early migration and differentiation. This study lacks suitable positive and negative controls that allow these conclusions to be drawn.

Several unpublished or non-peer reviewed studies reported behavioral responses as relevant endpoints of infrasound exposure. These data are not discussed, yet are the basis for several recent studies. In one more recent peer-reviewed behavioral rat study, adult male Wistar rats were classified as “superior endurance” and those as “inferior endurance” using the Rota-rod Treadmill (Yamamura et al., 1990). A range of frequencies and pressures were used to expose the rats for 60—150 minutes. Comparison of the pre-exposure endurance time on the Rota-Rod Treadmill with endurance after exposure to infrasound showed that the endurance time of the superior group after exposure to 16 Hz, 105 dB was not reduced. The endurance of the inferior group was reduced by exposure to 16 Hz, 105 dB after 10 minutes, to 16 Hz, 95 dB after 70 minutes, and to 16 Hz, 85 dB after 150 minutes. Of most relevance is the identification of a subset of rats that may be more responsive to infrasound due to their genetic makeup. There has been no follow-up regarding intra-strain susceptibility since this study.

More recent studies have focused on the mechanisms by which infrasound may disrupt normal brain function. As stated above, the infrasound exposures are acute—short-term, high dose. At the very least, researchers should document rat behaviors, pathologies, frank toxicities, and outcomes due to these high dose exposures in addition to measuring specific subcellular effects.

Some of the biological stress literature suggests that microglial activation can occur with heightened stress, but it appears to be short-lived and transitory affecting the autonomic nervous system and neuroendocrine system, resulting in multiple reported effects. To investigate the effect of infrasound on hippocampus-dependent learning and memory, Yuan et al. (2009) measure cognitive abilities and activation of molecular signaling pathways in order to determine the role of the neuronal signaling transduction pathway, BDNF-TRkB, in infrasound-induced impairment of memory and learning in the rat. Adult male Sprague-Dawley rats were exposed to infrasound of 16 Hz and 130 dB for 2 hours daily for 14 days. The acoustic conditions appeared to be well monitored and documented. The Morris water maze was used to determine spatial learning and retention, and molecular techniques were used to measure cell proliferation and concentrations of signaling pathway proteins. Using these semi-quantitative methods, rats exposed to infrasound demonstrated impaired hippocampal-dependent spatial learning acquisition and retention performance in the maze scheme compared with unexposed control rats, demonstrable downregulation of the BDNF-TRkB pathway, and decreased BrdU-labeled cell proliferation in the dentatel gyrus.

In another study, Du et al. (2010) hypothesize that microglial cells may be responsible for infrasound-induced stress. To test this hypothesis, 60 adult male Sprague-Dawley rats were exposed in an infrasonic chamber to 16 Hz at 130 dB for 2 hours. Brains were removed and sectioned and the hypothalamic paraventricular nucleus (PVN) examined. Primary microglial cells were isolated from whole brains of neonatal rats and grown in culture before they were exposed to infrasound under the same conditions as the whole animals. Molecular methods were used to identify the presence and levels of proteins indicative of biological stress (corticotrophin-releasing hormone (CRH) and corticotrophin-releasing hormone receptor (CRH type 1 receptor) in areas of the brain that control the stress response. Specifically, studies were done to determine whether microglial cells are involved in infrasound-response, changes in microglial activation, and CRH-R1 expression in vivo in the PVN and in vitro at time points after the two-hour infrasound exposure. The data show that the exposures resulted in microglial activation, beginning at 0.5 hours post exposure, and up-regulation of CRH-R1 expression. The magnitude of the response increased significantly from the control to 6 hours post exposure, returning to control levels, generally by 24 hours post-exposure. This study is well controlled, and while it does rely on a specific antagonist for dissecting the relative involvement of the neurons and the microglial cells, the data suggest that infrasound as administered in this study to rats can activate microglial cells, suggesting a possible mechanism for infrasound-induced ”stress” or nuisance at a physical level (i.e., proinflammatory cytokines causing sickness response behaviors).

In summary, there are no studies in which laboratory animals are subjected to exposures that mimic wind turbines. There is insufficient evidence from laboratory animal studies of effects of low frequency noise on the respiratory system. There is limited evidence that rats are a robust model for human infrasound exposure and effects. The reader is referred to Appendix G for specific study conditions. In any case, the infrasound levels and exposure conditions to which the rodents are exposed are adequate to cause pain to the rodents. When exposed to these levels of infrasound, there is some evidence of reversible molecular effects including short-lived biochemical alterations in cardiac and brain cells, suggesting a possible mechanism for high-dose, infrasound-induced effects in rats.

3.6 Health Impact Claims Associated with Noise and Vibration Exposure

The popular media contain a large number of articles that claim the noise and vibration from wind turbines adversely affect human health. In this section the Panel examines the physical and biological basis for these assertions. Additionally, the scientific articles from which these assertions are made are examined in light of the methods used and their limitations.

Pierpont (2009) has been cited as offering evidence of the physical effects of ILFN, referring to “Wind Turbine Syndrome” and its impact on the vestibular system—by disturbed sensory input to eyes, inner ears, and stretch and pressure receptors in a variety of body locations. The basis for the syndrome relies on data from research carried out for reasons (e.g., space missions) other than assessment of wind turbines on health. Such research can be valuable to understanding new conditions, however, when the presentation of data is incomplete, it can lead to inaccurate conclusions. A few such cases are mentioned here:

Pierpont (2009) notes that von Dirke and Parker (1994) show that the abdominal area resonates between 4 and 6 Hz and that wind turbines can produce infrasound within this range (due to the blade rotation rate). However, the von Dirke paper states that our bodies have evolved to be tolerant of the 4–6 Hz abdominal motion range: this range coincides with jogging and running. The paper also reveals that motion sickness (which was the focus of the study) only occurred when the vibrations to which people were subjected were between 0.01 and 0.5 Hz. The study exposed people to vibration from positive to negative 1 G forces. Subjects were also rotated around various axes to achieve the vibration levels and frequencies of interest in the study. Interpretation of these data may allow one to conclude that while the abdominal area has a resonance in a region at which there is infrasound being emitted by wind turbines, there will be no impact. Further, the infrasound emitted by wind turbines in the range of frequencies at which subjects did note motion sickness is orders of magnitude less than the level that induced motion sickness (see Table 2). So while a connection is made, the evidence at this point is not sufficient to draw a conclusion that a person's abdominal area or stretch point can be excited by turbine infrasound. If it were, this might lead to symptoms of motion sickness.

Pierpont (2009) points to a study by Todd et al. (2008) as potential proof that the inner ear may be playing a role in creating the symptoms of "Wind Turbine Syndrome." Todd et al. (2008) show that the vestibular system shows a best frequency response around 100 Hz. This is a fact, but again it is unclear how it relates to low frequency noise from wind turbines. The best frequency response was assessed by moving subjects' heads (knocking the side of the head) in a very specific direction because the portion of the inner ear that is being discussed acts as a gravitational sensor or an accelerometer; therefore, it responds to motion. A physical mechanism by which the audible sound produced by a wind turbine at 100 Hz would couple to the human body in a way to create the necessary motion to which this portion of the inner ear would respond is unknown.

More recently, Salt and Hullar (2010) have looked for something physical about the ear that could be responding to infrasonic frequencies. They describe how the outer (OHC) and inner (IHC) hair cells of the cochlea respond to different types of stimuli: the IHC responding to velocity and OHC responding to displacement. They discuss how the OHC respond to lower frequencies than the IHC, and how the OHC acts as an amplifier for the IHC. They state that it is known that low frequencies present in a sound signal can mask the higher frequencies—presumably because the OHC is not amplifying the higher frequency correctly when the OHC is responding to low frequency disturbances. However, they emphatically state that "although vestibular hair cells are maximally sensitive to low frequencies they typically do not respond to airborne infrasound. Rather, they normally respond to mechanical inputs resulting from head movements and positional changes with their output controlling muscle reflexes to maintain posture and eye position." It is completely unknown how the very few neural paths from the OHC to the brain respond, if they do at all (95% of the connections are between the IHC and the brain). So at this moment, inner ear experts have not found a method for airborne infrasound to impact the inner ear. The potential exists such that the OHC respond to infrasound, but that the functional role of the connection between the OHC and the brain remains unknown. Further, the modulation of the sound received at the IHC itself has not been shown to cause nausea, headaches, or dizziness.

In the discussion of amplitude-modulated noise, it was already noted that wind turbines produce audible sound in the low frequency regime (20–200Hz). It has been shown that the sound levels in this range from some turbines are above the levels for which subjects in a Korean study have complained of psychological effects (Jung & Cheung, 2008). O'Neal (2011) also shows that the sound pressure level for frequencies between 30 and 200 Hz from two modern wind turbines at roughly 310 m are above the threshold of hearing but below the criterion for creating window rattle or other perceptible vibrations. The issue of vibration is discussed more in the next section. It is noted that the amplitude-modulated noise is most likely at the heart of annoyance complaints. In addition, amplitude-modulated noise may be a source of sleep disturbance noted by survey respondents. However, direct health impacts have not been demonstrated.

3.6.a Vibration

Vibroacoustics disease (VAD) has been identified as a potential health impact of wind turbines in the Pierpont book. Most of the literature around VAD is attributed to Branco and Alves-Pereira. Related citations attributed to Takahashi (2001), Hedge and Rasmussen (1982) though are also provided. These studies all required very clear coupling to large vibration sources such as jackhammers and heavy equipment. The latter references focus on high levels of low frequency vibrations and noise. In particular, Rasmussen studied the response of people to vibrating floors and chairs. The vibration displacements in the study were on the order of 0.01 cm (or 1000 times larger than the motion found 100 m from a wind farm in a seismic study (Styles et al., 2005). Takahashi used loud speakers placed 2 m from subjects' bodies, only testing audible frequencies 20–50 Hz, using pressure levels on the order of 100–110 dB (roughly 30 dB higher than any sound measured from a wind turbine in this frequency range) to induce vibrations at various points on the body. The Hedge source is not a study but a bulleted list of points that seem to go along with a lecture in an ergonomics class for which no citations are provided. Branco's work is slightly different in that she considered very long-term exposures to moderately intense vibration inputs. While there may be possible connection to wind turbines, at present, the connection is not substantiated given the very low levels of vibration and airborne ILFN that have been measured from wind turbines.

While vibroacoustic disease may not be substantiated, vibration levels that lead to annoyance or feelings of uneasiness may be more plausible. Evidence for these responses is discussed below.

Pierpont refers to a paper by Findeis and Peters (2004). This reference describes a situation in Germany where complaints of disturbing sound and vibration were investigated through the measurement of the vibration and acoustics within the dwelling, noting that people complained about vibrations that were not audible. The one figure provided in the text shows that people were disturbed by what was determined to be structure-borne sound that was radiated by walls and floors at levels equivalent to 65 dB at 10 Hz and 40 dB at 100 Hz. The 10 Hz level is just below audible. The level reported at 100 Hz, however, is just above the hearing threshold. The authors concluded that the disturbances were due to a component of the HVAC system that coupled directly to the building.

The Findeis and Peters (2004), report is reminiscent of papers related to investigations of "haunted" spaces (Tandy, 1998, 1999). In these studies room frequencies around 18 Hz were found. The studies hypothesized that apparitions were the result of eye vibrations (the eye is sensitive to 18 Hz) induced by the room vibration field. In one of these studies, a ceiling fan was found to be the source of the vibration. In the other, the source was not identified.

When the source was identified in the previously mentioned studies, there appears to be an obvious physical coupling mechanism. In other situations it has been estimated that airborne disturbances have influenced structures. A NASA report from 1982 gives a figure that estimates the necessary sound pressure level at various frequencies to force vibrations in windows, walls, and floors of typical buildings (Stephens, 1982). The figure on page 14 of that report shows infrasound levels of 70–80 dB can induce wall and floor vibrations. On page 39 the report also shows some floor vibration levels that were associated with a wind turbine. On the graph these were the lowest levels of vibration when compared to vibrations from aircraft noise and sonic booms. Another figure on page 43 shows vibrations and perception across the infrasonic frequency range. Again, wind turbine data are shown, and they are below the perception line.

A second technical report (Kelley, 1985) from that timeframe describes disturbances from the MOD-1 wind turbine in Boone, North Carolina. This was a downwind turbine mounted on a truss tower. Out of 1000 homes within about 2 km, 10 homes experienced room vibrations under certain wind conditions. A careful measurement campaign showed that indeed these few homes had room vibrations related to the impulsive noise unique to downwind turbines. The report contains several findings including the following: 1) the disturbances inside the homes were linked to the impulsive sound generated by the turbine (due to tower wake/blade interaction) and not seismic waves, 2) the impulsive signal was feeding energy into the vibrational modes of the rooms, floors, and walls where the floor/wall modes were the only modes in the infrasonic range, 3) people felt the disturbance more than they heard it, 4) peak vibration values were measured in the frequency range 10–20 Hz (floor/wall resonances) and it was deduced that the wall facing the turbine was being excited, 5) the fact that only 10 homes out of 1000 (scattered in various directions around the turbine) were affected was shown to be related to complicated sound propagation paths, and 6) while the shape of the impulse itself was given much attention and was shown to be a driving force in the coupling to the structural vibrations, comments were made in the report to the effect that nonimpulsive signals with energy at the right frequency could couple into the structure. The report describes a situation in Oregon where resonances in the flow through an exhaust stack of a gas-run turbine plant had an associated slow modulation of the sound leading to annoyance near the plant. Again it was found that structural modes in nearby homes were being excited but this time by an acoustic field that was not impulsive in nature. This is an important point because modern wind turbines do not create impulsive noise with strong content around 20 Hz like the downwind turbine in North Carolina. Instead, they generate amplitude-modulated sound around 1 kHz as well as broadband infrasound (van den Berg, 2004). The broadband infrasound that also existed for the North Carolina turbine was not shown to be responsible for the disturbances. As well, the amplitude-modulated noise that existed was not shown to be responsible for the disturbances. So, while there are comparisons made to the gas turbine power plant and to the HVAC system component where the impulsiveness of the sound was not the same, direct comment on the effect of modern turbines on the vibration of homes is not possible.

A recent paper by Bolin et al. (2011), surveys much of the low frequency literature pertinent to modern wind turbines and notes that all measurements of indoor and outdoor levels of sound simultaneously do not show the same amplification and ringing of frequencies associated with structural resonances similar to what was found in North Carolina. Instead the sound inside is normally less than the sound outside the structure. Bolin et al. (2011) note that measurements indicate that the indoor ILFN from wind turbines typically comply with national guidelines (such as the Danish guideline for 44 dB(A) outside a dwelling). However, this does not preclude a situation where levels would be found to be higher than the standards. They propose that further investigations of an individual dwelling should be conducted if the measured difference between C-weighted and A-weighted sound pressure level of outdoor exposure is greater than 15 dB. A similar criterion is noted in the non-peer reviewed report by Kamperman et al. (2008).

Related to room vibration is window rattle. This topic is described in the NASA reports, discussed above (Stephens, 1982) and discussed in the articles by Jung and Cheung (2008) and O’Neal (2011). In these articles it has been noted that window rattle is often induced by vibrations between 5 and 9 Hz, and measurements from wind turbines show that there can be enough energy in this range to induce window rattle. Whether the window rattle then generates its own sound field inside a room at an amplitude great enough to disturb the human body is unknown.

Seismic transmission of vibration at the North Carolina site was considered. In that study the seismic waves were ruled out as too low of amplitude to induce the room vibrations that were generated. Related are two sets of measurements that were taken near wind farms to assess the potential impact of seismic activity on extremely sensitive seismic measurement stations (Styles, 2005, Schofield, 2010). One study considered both waves traveling in the ground and the coupling of airborne infrasound to the ground, showing that the dominant source of seismic motion is the Rayleigh waves in the ground transmitted directly by the tower, and that the airborne infrasound is not playing a role in creating measurable seismic motion. The two reports indicate that at 100 meters from a wind turbine farm (>6 turbines) the maximum motion that is induced is 120 nanometers (at about 1 Hz). A nanometer is 10^{-9} m. So this is 1.2×10^{-7} m of ground displacement. Extremely sensitive measuring devices have been used to detect this slight motion. To put the motion in perspective, the diameter of a human hair is on the order of 10^{-6} m. These findings indicate that seismic motion induced from one or two turbines is so small that it would be difficult to induce any physical or structural response.

Hessler and Hessler, (2010) reviewed various state noise limits and discussed them in connection with wind turbines. The article contains a few comments related to low frequency noise. It is stated that, “a link between health complaints and turbine noise has only been asserted based on what is essentially anecdotal evidence without any valid epidemiological studies or scientific proof of any kind.” The article states that if a metric for low frequency noise is needed, then a limit of 65 dB(C) could be used. This proposed criterion is not flexible for use in different environments such as rural vs. city. In this sense, Bolin et als’ suggestion of checking for a difference between C-weighted and A-weighted sound pressure level of outdoor exposure greater than 15 dB is more appropriate. This value of 15 dB, was based on past complaints associated with combustion turbines. The Bolin article, however, also cautions that obtaining accurate low frequency measurements for wind turbines is difficult because of the presence of wind. Even sophisticated windscreens cannot eliminate the ambient low frequency wind noise.

Leventhal (2006) notes that when hearing and deaf subjects are tested simultaneously, the subjects’ chests would resonate with sounds in the range of 50–80 Hz. However, the amplitude of the sound had to be 40–50 dB higher than the human hearing threshold for the deaf subjects to report the chest vibration. This leads one to conclude that chest resonance in isolation should not be associated with inaudible sound. If a room is vibrating due to a structural resonance, such levels may be obtained. Again, this effect has never been measured associated with a modern wind turbine.

The stimulation of house resonances and self-reported ill-effects due to a modern wind turbine appear in a report by independent consultants that describes pressure measurements taken inside and outside of a home in Falmouth Massachusetts in the spring of 2011 (Ambrose & Rand, 2011). The measurements were taken at roughly 500 meters from a single 1.65 MW stall-regulated turbine when the wind speeds were relatively high: 20-30 m/s at hub height. The authors noted feeling ill when the dB(A) levels indoors were between 18 and 24 (with a corresponding dB(G) level of 51-64). They report that they felt effects both inside and outside but preferred to be outside where the dB(A) levels ranged from 41-46 (with corresponding dB(G) levels from 54-65.) This is curious because weighted measurements account for human response and the weighted values were higher outside. However, the actual dB(L) levels were higher inside.

The authors present some data indicating that the G-weighted value of the pressure signal is often greater than 60 dB(G), the averaged threshold value proposed by Salt and Hullar (2011) for OHC activation. However, the method used to obtain the data is not presented, and the time scale over which the data are presented (< 0.015 seconds or 66 Hz) is too short to properly capture the low frequency content.

The data analysis differed from the common standard of practice in an attempt to highlight weaknesses in the standard measurement approach associated with the capture of amplitude modulation and ILFN. This departure from the standard is a useful step in defining a measurement technique such as that called for in a report by HGC Engineering (HGC, 2010), that notes policy making entities should “consider adopting or endorsing a proven measurement procedure that could be used to quantify noise at infrasonic frequencies.”

The measurements by Ambrose and Rand (2011) show a difference in A and C weighted outdoor sound levels of around 15 dB at the high wind speeds (which is Bolin et. al.’s recommended value for triggering further interior investigations). The simultaneous indoor and outdoor measurements indicate that at very low frequencies (2-6 Hz) the indoor pressure levels are greater than those outdoors. It is useful to note that the structural forcing at the blade-passage-frequency, the time delay and the subsequent ringing that was present in the Boone homes (Kelley, 1985) is not demonstrated by Ambrose and Rand (2011). This indicates that the structural coupling is not forced by the amplitude modulation and is due to a much subtler process. Importantly, while there is an amplification at these lower frequencies, the indoor levels (unweighted) are still far lower than any levels that have ever been shown to cause a physical response (including the activation of the OHC) in humans.

The measurements did reveal a 22.9 Hz tone that was amplitude modulated at approximately the blade passage frequency. The source of the tone was not identified, and no indication as to whether the tone varied with wind speed was provided, a useful step to help determine whether the tone is aerodynamically generated. The level of this tone is shown to be higher than the OHC activation threshold. The 22.9 Hz tone did not couple to the structure and showed the normal attenuation from outside to inside the structure. In order to determine if the results that show potential tonal activation of the OHC are generalizable, it is necessary to identify the source of this tone which could be unique to stall-regulated turbines or even unique to this specific brand of turbine.

Finally, the measurements shown in the report are atypical within the wind turbine measurement literature and the data analysis is not fully described. Also, the report offers no plausible coupling mechanism of the sound waves to the body beyond that proposed by Salt and Hullar (2011). Because of this, the results are suggestive but require corroboration of the measurements and scientifically based mechanisms for human health impact.

3.6.b Summary of Claimed Health Impacts

In this section, the potential health impacts due to noise and vibration from wind turbines was discussed. Both the infrasonic and low frequency noise ranges were considered. Assertions that infrasound and low frequency noise from turbines affect the vestibular system either through airborne coupling to humans are not empirically supported. In the multitude of citations given in the popular media as to methods in which the vestibular system is influenced, all refer to situations in which there is direct vibration coupling to the body or when the wave amplitudes are orders of magnitudes greater than those produced by wind turbines. Recent research has found one potential path in the auditory system, the OHC, in which infrasound might be sensed. There is no evidence, however, that when the OHC sense infrasound, it then leads to any of the symptoms reported by complainants. That the infrasound and low frequency noise couple to humans through the forcing of structural vibration is plausible but has not been demonstrated for modern wind turbines. In addition, should it be shown that such a coupling occurs, research indicates that the coupling would be transient and highly dependent on wind conditions and localized to very few homes surrounding a turbine.

Seismic activity near a turbine due to vibrations transmitted down the tower has been measured, and the levels are too low to produce vibrations in humans.

The audible noise from wind turbines, in particular the amplitude modulated trailing edge noise, does exist, changes level based on atmospheric conditions, can change character from swish to thump-based on atmospheric effects, and can be perceived from home to home differently based on propagation effects. This audible sound has been noted by complainants as a source of annoyance and a cause for sleep disruption. Some authors have proposed nighttime noise regulations and regulations based on shorter time averages (vs. annual averages) as a means to reduce annoyance from this noise source. Some have conjectured that the low frequency content of the amplitude-modulated noise is responsible for the annoyance. They have proposed that the difference between the measured outdoor A- and C- weighted sound pressure levels could be used to identify situations in which the low frequency content is playing a larger role. Further, they note that this difference might be used as part of a regulation as a means to reduce annoyance.

Chapter 4

Findings

Based on the detailed review of the scientific literature and other available reports and consideration of the strength of scientific evidence, the Panel presents findings relative to three factors associated with the operation of wind turbines: noise and vibration, shadow flicker, and ice throw. The findings that follow address specifics in each of these three areas.

4.1 Noise

4.1.a Production of Noise and Vibration by Wind Turbines

1. Wind turbines can produce unwanted sound (referred to as noise) during operation. The nature of the sound depends on the design of the wind turbine. Propagation of the sound is primarily a function of distance, but it can also be affected by the placement of the turbine, surrounding terrain, and atmospheric conditions.
    a. Upwind and downwind turbines have different sound characteristics, primarily due to the interaction of the blades with the zone of reduced wind speed behind the tower in the case of downwind turbines.
    b. Stall regulated and pitch controlled turbines exhibit differences in their dependence of noise generation on the wind speed
    c. Propagation of sound is affected by refraction of sound due to temperature gradients, reflection from hillsides, and atmospheric absorption. Propagation effects have been shown to lead to different experiences of noise by neighbors.
    d. The audible, amplitude-modulated noise from wind turbines ("whooshing") is perceived to increase in intensity at night (and sometimes becomes more of a "thumping") due to multiple effects: i) a stable atmosphere will have larger wind gradients, ii) a stable atmosphere may refract the sound downwards instead of upwards, iii) the ambient noise near the ground is lower both because of the stable atmosphere and because human generated noise is often lower at night.
2. The sound power level of a typical modern utility scale wind turbine is on the order of 103 dB(A), but can be somewhat higher or lower depending on the details of the design and the rated power of the turbine. The perceived sound decreases rapidly with the distance from the wind turbines. Typically, at distances larger than 400 m, sound

pressure levels for modern wind turbines are less than 40 dB(A), which is below the level associated with annoyance in the epidemiological studies reviewed.

3. Infrasound refers to vibrations with frequencies below 20 Hz. Infrasound at amplitudes over 100–110 dB can be heard and felt. Research has shown that vibrations below these amplitudes are not felt. The highest infrasound levels that have been measured near turbines and reported in the literature near turbines are under 90 dB at 5 Hz and lower at higher frequencies for locations as close as 100 m.
4. Infrasound from wind turbines is not related to nor does it cause a “continuous whooshing.”
5. Pressure waves at any frequency (audible or infrasonic) can cause vibration in another structure or substance. In order for vibration to occur, the amplitude (height) of the wave has to be high enough, and only structures or substances that have the ability to receive the wave (resonant frequency) will vibrate.

4.1.b Health Impacts of Noise and Vibration

1. Most epidemiologic literature on human response to wind turbines relates to self-reported “annoyance,” and this response appears to be a function of some combination of the sound itself, the sight of the turbine, and attitude towards the wind turbine project.
    a. There is limited epidemiologic evidence suggesting an association between exposure to wind turbines and annoyance.
    b. There is insufficient epidemiologic evidence to determine whether there is an association between noise from wind turbines and annoyance independent from the effects of seeing a wind turbine and vice versa.
2. There is limited evidence from epidemiologic studies suggesting an association between noise from wind turbines and sleep disruption. In other words, it is possible that noise from some wind turbines can cause sleep disruption.
3. A very loud wind turbine could cause disrupted sleep, particularly in vulnerable populations, at a certain distance, while a very quiet wind turbine would not likely disrupt even the lightest of sleepers at that same distance. But there is not enough evidence to

provide particular sound-pressure thresholds at which wind turbines cause sleep disruption. Further study would provide these levels.

4. Whether annoyance from wind turbines leads to sleep issues or stress has not been sufficiently quantified. While not based on evidence of wind turbines, there is evidence that sleep disruption can adversely affect mood, cognitive functioning, and overall sense of health and well-being.
5. There is insufficient evidence that the noise from wind turbines is *directly (i.e., independent from an effect on annoyance or sleep)* causing health problems or disease.
6. Claims that infrasound from wind turbines directly impacts the vestibular system have not been demonstrated scientifically. Available evidence shows that the infrasound levels near wind turbines cannot impact the vestibular system.
    a. The measured levels of infrasound produced by modern upwind wind turbines at distances as close as 68 m are well below that required for non-auditory perception (feeling of vibration in parts of the body, pressure in the chest, etc.).
    b. If infrasound couples into structures, then people inside the structure could feel a vibration. Such structural vibrations have been shown in other applications to lead to feelings of uneasiness and general annoyance. The measurements have shown no evidence of such coupling from modern upwind turbines.
    c. Seismic (ground-carried) measurements recorded near wind turbines and wind turbine farms are unlikely to couple into structures.
    d. A possible coupling mechanism between infrasound and the vestibular system (via the Outer Hair Cells (OHC) in the inner ear) has been proposed but is not yet fully understood or sufficiently explained. Levels of infrasound near wind turbines have been shown to be high enough to be sensed by the OHC. However, evidence does not exist to demonstrate the influence of wind turbine-generated infrasound on vestibular-mediated effects in the brain.
    e. Limited evidence from rodent (rat) laboratory studies identifies short-lived biochemical alterations in cardiac and brain cells in response to short exposures to emissions at 16 Hz and 130 dB. These levels exceed measured infrasound levels from modern turbines by over 35 dB.

7. There is no evidence for a set of health effects, from exposure to wind turbines, that could be characterized as a "Wind Turbine Syndrome."
8. The strongest epidemiological study suggests that there is not an association between noise from wind turbines and measures of psychological distress or mental health problems. There were two smaller, weaker, studies: one did note an association, one did not. Therefore, we conclude the weight of the evidence suggests no association between noise from wind turbines and measures of psychological distress or mental health problems**.**
9. None of the limited epidemiological evidence reviewed suggests an association between noise from wind turbines and pain and stiffness, diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, and headache/migraine.

4.2 Shadow Flicker

4.2.a Production of Shadow Flicker

Shadow flicker results from the passage of the blades of a rotating wind turbine between the sun and the observer.

1. The occurrence of shadow flicker depends on the location of the observer relative to the turbine and the time of day and year.
2. Frequencies of shadow flicker elicited from turbines is proportional to the rotational speed of the rotor times the number of blades and is generally between 0.5 and 1.1 Hz for typical larger turbines.
3. Shadow flicker is only present at distances of less than 1400 m from the turbine.

4.2.b Health Impacts of Shadow Flicker

1. Scientific evidence suggests that shadow flicker does not pose a risk for eliciting seizures as a result of photic stimulation.
2. There is limited scientific evidence of an association between annoyance from prolonged shadow flicker (exceeding 30 minutes per day) and potential transitory cognitive and physical health effects.

4.3 Ice Throw

4.3.a Production of Ice Throw

Ice can fall or be thrown from a wind turbine during or after an event when ice forms or accumulates on the blades.

1. The distance that a piece of ice may travel from the turbine is a function of the wind speed, the operating conditions, and the shape of the ice.
2. In most cases, ice falls within a distance from the turbine equal to the tower height, and in any case, very seldom does the distance exceed twice the total height of the turbine (tower height plus blade length).

4.3.b Health Impacts of Ice Throw

1. There is sufficient evidence that falling ice is physically harmful and measures should be taken to ensure that the public is not likely to encounter such ice.

4.4 Other Considerations

In addition to the specific findings stated above for noise and vibration, shadow flicker and ice throw, the Panel concludes the following:

1. Effective public participation in and direct benefits from wind energy projects (such as receiving electricity from the neighboring wind turbines) have been shown to result in less annoyance in general and better public acceptance overall.

Chapter 5

Best Practices Regarding Human Health Effects Of Wind Turbines

Broadly speaking, the term “best practice” refers to policies, guidelines, or recommendations that have been developed for a specific situation. Implicit in the term is that the practice is based on the best information available at the time of its institution. A best practice may be refined as more information and studies become available. The panel recognizes that in countries which are dependent on wind energy and are protective of public health, best practices have been developed and adopted.

In some cases, the weight of evidence for a specific practice is stronger than it is in other cases. Accordingly, best practice* may be categorized in terms of the evidence available, as shown in Table 3:

Table 3

Descriptions of Three Best Practice Categories

Category	**Name**	**Description**
1	Research Validated Best Practice	A program, activity, or strategy that has the highest degree of proven effectiveness supported by objective and comprehensive research and evaluation.
2	Field Tested Best Practice	A program, activity, or strategy that has been shown to work effectively and produce successful outcomes and is supported to some degree by subjective and objective data sources.
3	Promising Practice	A program, activity, or strategy that has worked within one organization and shows promise during its early stages for becoming a best practice with long-term sustainable impact. A promising practice must have some objective basis for claiming effectiveness and must have the potential for replication among other organizations.

**These categories are based on those suggested in "Identifying and Promoting Promising Practices." Federal Register, Vol. 68. No 131. 131. July 2003.*
www.acf.hhs.gov/programs/ccf/about_ccf/gbk_pdf/pp_gbk.pdf

5.1 Noise

Evidence regarding wind turbine noise and human health is limited. There is limited evidence of an association between wind turbine noise and both annoyance and sleep disruption, depending on the sound pressure level at the location of concern. However, there are no research-based sound pressure levels that correspond to human responses to noise. A number of countries that have more experience with wind energy and are protective of public health have developed guidelines to minimize the possible adverse effects of noise. These guidelines consider time of day, land use, and ambient wind speed. Table 4 summarizes the guidelines of Germany (in the categories of industrial, commercial and villages) and Denmark (in the categories of sparsely populated and residential). The sound levels shown in the table are for nighttime and are assumed to be taken immediately outside of the residence or building of concern. In addition, the World Health Organization recommends a maximum nighttime sound pressure level of 40 dB(A) in residential areas. Recommended setbacks corresponding to these values may be calculated by software such as WindPro or similar software. Such calculations are normally to be done as part of feasibility studies. The Panel considers the guidelines shown below to be Promising Practices (Category 3) but to embody some aspects of Field Tested Best Practices (Category 2) as well.

Table 4

Promising Practices for Nighttime Sound Pressure Levels by Land Use Type

Land Use	**Sound Pressure Level, dB(A) Nighttime Limits**
Industrial	70
Commercial	50
Villages, mixed usage	45
Sparsely populated areas, 8 m/s wind*	44
Sparsely populated areas, 6 m/s wind*	42
Residential areas, 8 m/s wind*	39
Residential areas, 6 m/s wind*	37

**measured at 10 m above ground, outside of residence or location of concern*

The time period over which these noise limits are measured or calculated also makes a difference. For instance, the often-cited World Health Organization recommended nighttime noise cap of 40 dB(A) is averaged over one year (and does not refer specifically to wind turbine noise). Denmark's noise limits in the table above are calculated over a 10-minute period. These limits are in line with the noise levels that the epidemiological studies connect with insignificant reports of annoyance.

The Panel recommends that noise limits such as those presented in the table above be included as part of a statewide policy regarding new wind turbine installations. In addition, suitable ranges and procedures for cases when the noise levels may be greater than those values should also be considered. The considerations should take into account trade-offs between environmental and health impacts of different energy sources, national and state goals for energy independence, potential extent of impacts, etc.

The Panel also recommends that those involved in a wind turbine purchase become familiar with the noise specifications for the turbine and factors that affect noise production and noise control. Stall and pitch regulated turbines have different noise characteristics, especially in high winds. For certain turbines, it is possible to decrease noise at night through suitable control measures (e.g., reducing the rotational speed of the rotor). If noise control measures are to be considered, the wind turbine manufacturer must be able to demonstrate that such control is possible.

The Panel recommends an ongoing program of monitoring and evaluating the sound produced by wind turbines that are installed in the Commonwealth. IEC 61400-11 provides the standard for making noise measurements of wind turbines (International Electrotechnical Commission, 2002). In general, more comprehensive assessment of wind turbine noise in populated areas is recommended. These assessments should be done with reference to the broader ongoing research in wind turbine noise production and its effects, which is taking place internationally. Such assessments would be useful for refining siting guidelines and for developing best practices of a higher category. Closer investigation near homes where outdoor measurements show A and C weighting differences of greater than 15 dB is recommended.

5.2 Shadow Flicker

Based on the scientific evidence and field experience related to shadow flicker, Germany has adopted guidelines that specify the following:

1. Shadow flicker should be calculated based on the astronomical maximum values (i.e., not considering the effect of cloud cover, etc.).
2. Commercial software such as WindPro or similar software may be used for these calculations. Such calculations should be done as part of feasibility studies for new wind turbines.
3. Shadow flicker should not occur more than 30 minutes per day and not more than 30 hours per year at the point of concern (e.g., residences).
4. Shadow flicker can be kept to acceptable levels either by setback or by control of the wind turbine. In the latter case, the wind turbine manufacturer must be able to demonstrate that such control is possible.

The guidelines summarized above may be considered to be a Field Tested Best Practice (Category 2). Additional studies could be performed, specifically regarding the number of hours per year that shadow flicker should be allowed, that would allow them to be placed in Research Validated (Category 1) Best Practices.

5.3 Ice Throw

Ice falling from a wind turbine could pose a danger to human health. It is also clear that the danger is limited to those times when icing occurs and is limited to relatively close proximity to the wind turbine. Accordingly, the following should be considered Category 1 Best Practices.

1. In areas where icing events are possible, warnings should be posted so that no one passes underneath a wind turbine during an icing event and until the ice has been shed.
2. Activities in the vicinity of a wind turbine should be restricted during and immediately after icing events in consideration of the following two limits (in meters).

For a turbine that may not have ice control measures, it may be assumed that ice could fall within the following limit:

$$x_{\max,\,throw} = 1.5\left(2R + H\right)$$

Where: *R* = rotor radius (m), *H* = hub height (m)

For ice falling from a stationary turbine, the following limit should be used:

$$x_{\max,\,fall} = U\left(R + H\right)/15$$

Where: *U* = maximum likely wind speed (m/s)

The choice of maximum likely wind speed should be the expected one-year return maximum, found in accordance to the International Electrotechnical Commission's design standard for wind turbines, IEC 61400-1.

Danger from falling ice may also be limited by ice control measures. If ice control measures are to be considered, the wind turbine manufacturer must be able to demonstrate that such control is possible.

5.4 Public Participation/Annoyance

There is some evidence of an association between participation, economic or otherwise, in a wind turbine project and the annoyance (or lack thereof) that affected individuals may express. Accordingly, measures taken to directly involve residents who live in close proximity to a wind turbine project may also serve to reduce the level of annoyance. Such measures may be considered to be a Promising Practice (Category 3).

5.5 Regulations/Incentives/Public Education

The evidence indicates that in those parts of the world where there are a significant number of wind turbines in relatively close proximity to where people live, there is a close coupling between the development of guidelines, provision of incentives, and educating the public. The Panel suggests that the public be engaged through such strategies as education, incentives for community-owned wind developments, compensations to those experiencing documented loss of property values, comprehensive setback guidelines, and public education related to renewable energy. These multi-faceted approaches may be considered to be a Promising Practice (Category 3).

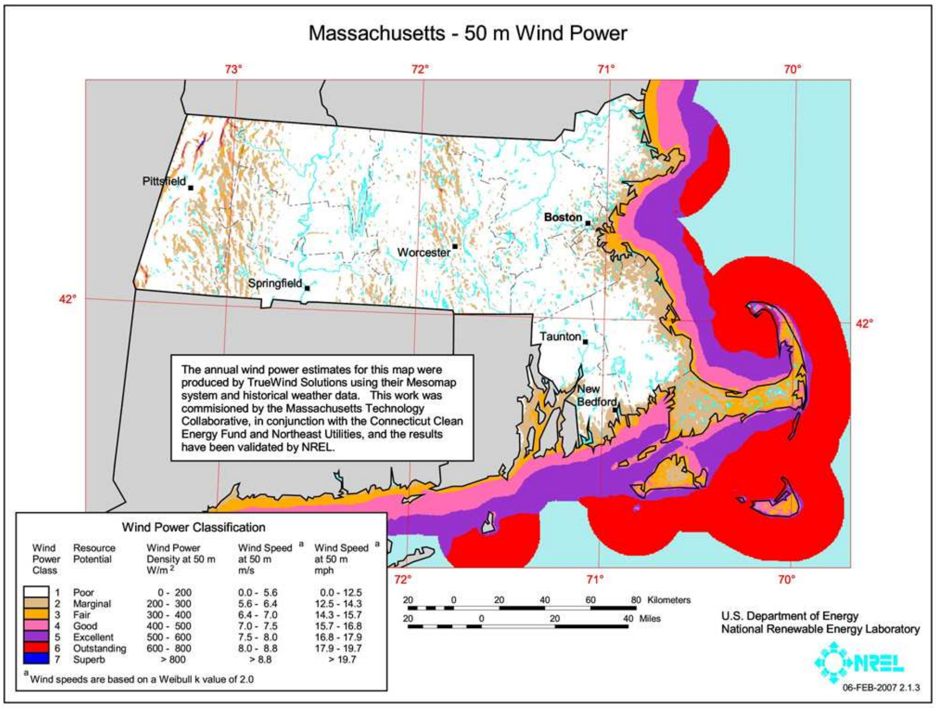
Appendix A:

Wind Turbines - Introduction to Wind Energy

Although wind energy for bulk supply of electricity is a relatively new technology, the historical precedents for it go back a long way. They are descendents of mechanical windmills that first appeared in Persia as early as the 7th century (Vowles, 1932) and then re-appeared in northern Europe in the Middle Ages. They were considerably developed during the 18th and 19th centuries, and then formed the basis for the first electricity generating wind turbine in the late 19th century. Development continued sporadically through the mid 20th century, with modern turbines beginning to emerge in the 1970's. It was the introduction of other technologies, such as electronics, computers, control theory, composite materials, and computer-based simulation capability that led to the successful development of the large scale, autonomously operating wind turbines that have become so widely deployed over the past twenty years.

The wind is the most important external factor in wind energy. It can be thought of as the "fuel" of the wind turbine, even though it is not consumed in the process. The wind determines the amount of energy that is produced, and is therefore referred to as the resource. The wind resource can vary significantly, depending on the location and the nature of the surface. In the United States, the Great Plains have a relatively energetic wind resource. In Massachusetts, winds tend to be relatively low inland, except for mountaintops and ridges. The winds tend to be higher close to the coast and then increase offshore. Average offshore wind speeds generally increase with distance from shore as well. The wind resource of Massachusetts is illustrated in

Figure AA.1: Map of the Massachusetts Wind Resource (From National Renewable Energy Laboratory, http://www.windpoweringamerica.gov/images/windmaps/ma_50m_800.jpg)



The annual wind power estimates for this map were produced by TrueWind Solutions using their Mesomap system and historical weather data. This work was commisioned by the Massachusetts Technology Collaborative, in conjunction with the Connecticut Clean Energy Fund and Northeast Utilities, and the results have been validated by NREL.

Wind Power Classification

Wind Power Class		Resource Potential	Wind Power Density at 50 m W/m ^{2}	Wind Speed [a] at 50 m m/s	Wind Speed [a] at 50 m mph
☐	1	Poor	0 - 200	0.0 - 5.6	0.0 - 12.5
🟫	2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
🟧	3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
🟪	4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
🟪	5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
🟥	6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
🟦	7	Superb	> 800	> 8.8	> 19.7

[a] Wind speeds are based on a Weibull k value of 2.0

This section summarizes the basic characteristics of the wind in so far as they relate to wind turbine power production. Much more detail on this topic is provided in (Manwell et al., 2009). The wind will also affect the design of the wind turbines, and for this purpose it is referred to as an "external design condition." This aspect of the wind is discussed in more detail in a later section.

AA.1 Origin of the Wind

The wind originates from sunlight due to the differential heating of various parts of the earth. This differential heating produces zones of high and low pressure, resulting in air movement. The motion of the air is also affected by earth's rotation. Considerations regarding the wind insofar as it relates to wind turbine operation include the following: (i) the winds aloft (geostrophic wind), (ii) atmospheric boundary layer meteorology, (iii) the variation of wind speed with height, (iv) surface roughness, and (v) turbulence.

The geostrophic wind is the wind in the upper atmosphere, which results from the combined effects of the pressure gradient and the earth's rotation (via the Coriolis force). The gradient wind can be thought of as an extension of the geostrophic wind, the difference in this case being that centrifugal effects are included. These result from curved isobars (lines of constant pressure) in the atmosphere. It is these upper atmosphere winds that are the source of most of the energy that eventually impinges on wind turbines. The energy in the upper atmosphere is transferred down closer to the surface via a variety of mechanisms, most notably turbulence, which is generated mechanically (via surface roughness) and thermally (via the rising of warm air and falling of cooler air).

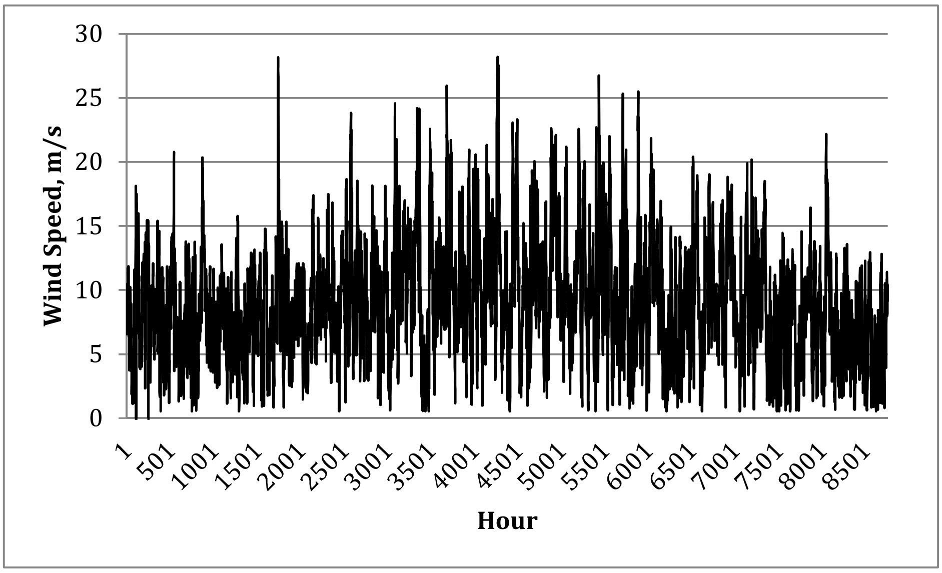
Although driven by higher altitude winds, the wind near the surface is affected by the surrounding topography (such as mountains and ridges) and surface conditions (such as tree cover or presence of buildings).

AA.2 Variability of the Wind

One of the singular characteristics of the wind is its variability, both temporal and spatial. The temporal variability includes: (i) short term (gusts and turbulence), (ii) moderately short term (e.g., hr to hr means), (iii) diurnal (variations over a day), (iv) seasonal, and (v) inter-annual (year to year). The wind may vary spatially as well, both from one location to another or with height above ground.

Figure AA.2 illustrates the variability of the hourly average wind speeds for one year at one location.

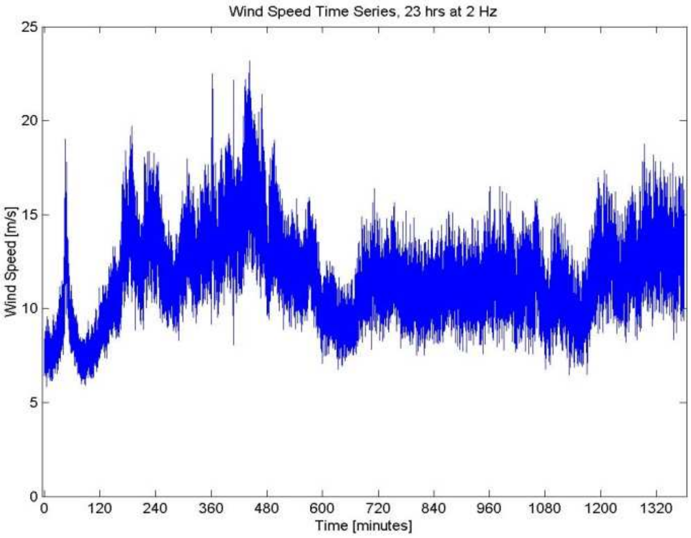
Figure AA.2: Typical hourly wind speeds over a year



As can be seen, the hourly average wind speed in this example varies significantly over the year, ranging from zero to nearly 30 m/s.

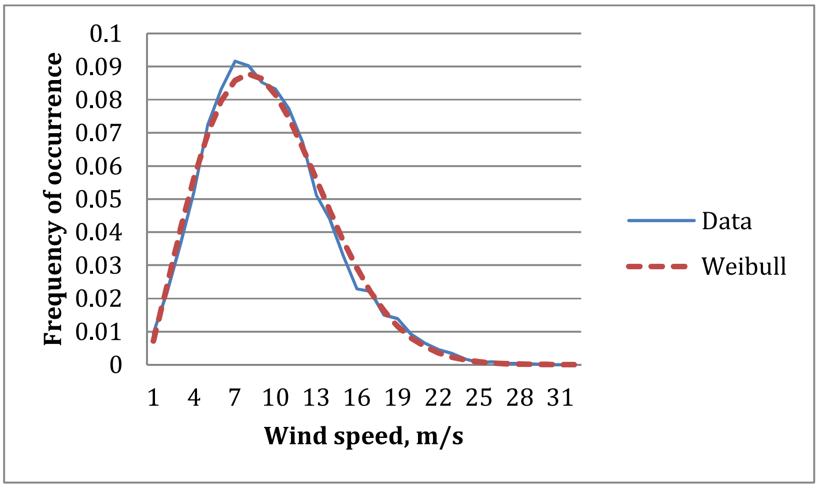
Figure AA.3 illustrates wind speed at another location recorded twice per second over a 23-hour period. There is significant variability here as well. Much of this variability in this figure is associated with short-term fluctuations, or turbulence. Turbulence has some effect on power generation, but it has a more significant effect on the design of wind turbines, due to the material fatigue that it tends to engender. Turbulence is discussed in more detail in a later section.

Figure AA.3: Typical wind data, sampled at 2 Hz for a 23-hr period



In spite of the variability in the wind time series, summary characteristics have much less variability. For example, the annual mean wind speed at a given location is generally within +/- 10% of the long-term mean at that site. Furthermore, the distribution of wind speeds, that is to say the frequency of occurrence of winds in various wind speed ranges, also tends to be similar from year. The general shape of such distributions is also similar from one location to another, even if the means are different. In fact, statistical models such as the Weibull distribution can be used to model the occurrences of various wind speeds in most locations on the earth. For example, the number of occurrences of wind speed in various ranges from the data set illustrated in Figure AA.2 are shown in Figure AA.4, together with the those occurrences as modeled by the Weibull distribution.

Figure AA.4: Typical frequency of occurrence of wind speeds, based on data and statistical model



The Weibull distribution’s probability density function is given by:

$$p(U)=\left(\frac{k}{c}\right)\left(\frac{U}{c}\right)^{k-1}\exp\left[-\left(\frac{U}{c}\right)^{k}\right] \qquad (1)$$

Where c = Weibull scale factor (m/s) and k = Weibull shape factor (dimensionless)

For the purposes of modeling the occurrences of wind speeds, the scale and shape factors may be approximated as follows:

$$k\approx\left(\frac{\sigma_U}{\overline{U}}\right)^{-1.086} \qquad (2)$$

$$c\approx\overline{U}\left(0.568+0.433/k\right)^{-(1/k)} \qquad (3)$$

Where $\overline{U}$ is the long-term mean wind speed (m/s, based on 10 min or hourly averages) and σ_U is the standard deviation of the wind speed, based on the same 10 min or hourly averages.

AA.3 Power in the Wind

The power available in the wind can be predicted from the fundamental principles of fluid mechanics. First of all, the energy per unit mass of a particle of air is given simply by ½ times the square of the velocity, U (m/s). The mass flow rate of the air (kg/s) through a given area A (m^2) perpendicular to the direction of the wind is $\dot{m} = \rho A U$, where ρ is the density of the air (kg/m^3). The power in the wind per unit area, P/A, (W/m^2) is then:

$$P/A = (\dot{m}/A)\frac{1}{2}U^2 = \frac{1}{2}\rho U^3 \tag{4}$$

AA.4 Wind Shear

Wind shear is the variation of wind speed with height. Wind shear has relevance to power generation, to turbine design, and to noise generation. The variation of wind speed with height is typically modeled with a power law as follows:

$$U_2 = U_1[h_2/h_1]^{\alpha} \tag{5}$$

Where U_1 = speed at reference height h_1, U_2 is the wind speed to be estimated at height h_2 and α is the power law exponent. Values of the exponent typically range from a 0.1 for smooth surfaces to 0.4 for very rough surfaces (such as forests or built-up areas.)

Wind shear can also be affected by the stability of the atmosphere. Equations have been developed that allow the incorporation of stability parameters in the analysis, but these too are outside the scope of this overview.

AA.5 Wind and Wind Turbine Structural Issues

As discussed previously, the wind is of particular interest in wind turbine applications, since it is the source of the energy. It is also the source of significant structural loads that the turbine must be able to withstand. Some of these loads occur when the turbine is operating; others occur when it is stopped. Extreme winds, for example, are likely to affect a turbine when it is stopped. High winds with sudden directional change during operation can also induce high loads. Turbulence during normal operation results in fatigue. The following is a summary of the key aspects of the wind that affect the design of wind turbines. More details may be found in (Manwell et al., 2009).

AA.5.a Turbulence

Turbulence in the wind can have significant effect on the structure of a wind turbine as well as its operation, and so it must be considered in the design process. The term "turbulence" refers to the short-term variations in the speed and direction of the wind. It manifests itself as apparently random fluctuations superimposed upon a relatively steady mean flow. Turbulence is not actually random, however. It has some very distinct characteristics, at least in a statistical sense.

Turbulence is characterized by a number of measures. These include: (i) turbulence intensity, (ii) turbulence probability density functions (pdf), (iii) autocorrelations, (iv) integral time scales and length scales, and (v) power spectral density functions. Discussion of the physics of turbulence is outside the scope of this overview.

AA.5.b Gusts

A gust is discrete increase and then decrease in wind speed, possibly associated with a change in wind direction, which can be of significance to the design of a wind turbine. Gusts are typically associated with turbulence.

AA.5.c Extreme Winds

Extreme winds need to be considered for the design of a wind turbine. Extreme winds are normally associated with storms. They occur relatively rarely, but often enough that the possibility of their occurring cannot be ignored. Statistical models, such as the Gumbel distribution (Gumbel, 1958), are used to predict the likelihood of such winds occurring at least once every 50 or 100 years. Such intervals are called return periods.

AA.5.d Soils

Soils are also important for the design and installation of a wind turbine. In particular, the nature of the soil will affect the design of the wind turbine foundations. Discussion of soils is outside the scope of this overview.

AA.6 Wind Turbine Aerodynamics

The heart of the wind turbine is the rotor. This is a device that extracts the kinetic energy from the wind and converts it into a mechanical form. Below is a summary of wind turbine rotor aerodynamics. More details may be found in (Manwell et al., 2009).

A wind turbine rotor is comprised of blades that are attached to a hub. The hub is in turn attached to a shaft (the main shaft) which transfers the energy through the remainder of the drive train to the generator where is it converted to electricity. The maximum power that a rotor can extract from the wind is first of all limited by the power in the wind, which passes through an area defined by the passage of the rotor. At the present time, most wind turbines utilize a rotor with a horizontal axis. That is, the axis of rotation is (nominally) parallel to the earth's surface. Accordingly, the area that is swept out by the rotor is circular. Assuming a rotor radius of R (m), the maximum power P (W) available in the wind is:

$$P = \frac{1}{2}\rho\pi R^2 U^3 \tag{6}$$

Early in the 20th century, it was shown by Betz (among others, see [4]) that the maximum power that could be extracted was less than the power in the wind; in fact, it was 16/27 times that value. Betz' work led to the definition of a power coefficient, C_p, which expresses the ratio of the actual power extracted by a rotor to the power in the wind. When considering efficiencies of other components in the drive train, as expressed by the η, the total power out a wind turbine, P_{WT}, would be given by:

$$P_{WT} = C_p \eta \frac{1}{2}\rho\pi R^2 U^3 \tag{7}$$

The maximum value of the power coefficient, known as the Betz limit, is thus 16/27.

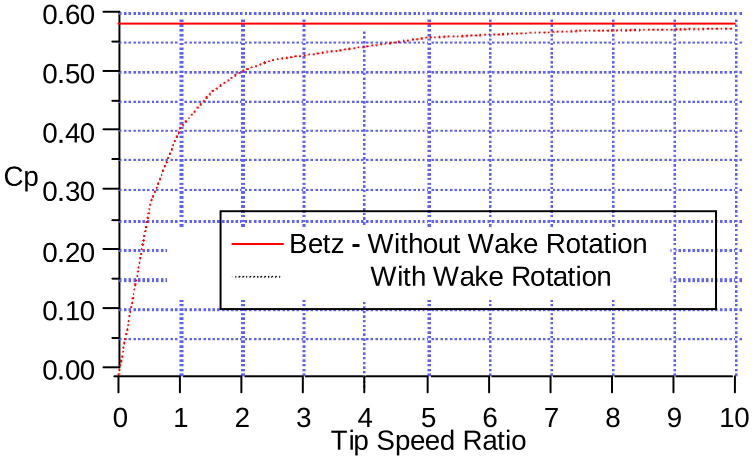
Betz' original analysis was based on the fundamental principles of fluid mechanics including linear momentum theory. It also included the following assumptions: (i) homogenous, incompressible, steady state fluid flow; (ii) no frictional drag; (iii) a rotor with an infinite number of (very small) blades; (iv) uniform thrust over the rotor area; (v) a non-rotating wake; and (vi) the static pressure far upstream and far downstream of the rotor that is equal to the undisturbed ambient static pressure.

A real rotor operating on a horizontal axis will result in a rotating wake. Some of the energy in the wind will go into that rotation and will not be available for conversion into mechanical power. The result is that the maximum power coefficient will actually be less than the Betz limit. The derivation of the maximum power coefficient for the rotating wake case use a number of terms: (i) the rotational speed of turbine rotor, Ω, in radians/sec; (ii) tip speed ratio, $\lambda = \Omega R/U$; (iii) local speed ratio, $\lambda_r = \lambda\ r/R$; (iv) rotational speed of wake, ω; (v) an axial induction factor, a, which relates the free stream wind speed to the wind speed at the rotor and the wind speed in the far wake ($U_{rotor} = (1-a)U_{free\ stream}$ and $U_{wake} = (1-2a)U_{free\ stream}$); and (vi) an angular induction factor, $a' = \omega/2\ \Omega$. According to this analysis, the maximum possible power coefficient is given by:

$$C_{P,\max} = \frac{8}{\lambda^2}\int_0^{\lambda} a'(1-a)\lambda_r^3 d\lambda_r \tag{8}$$

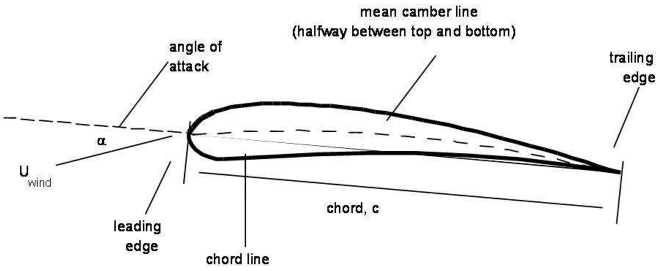
The maximum power coefficient for a rotor with a rotating wake and the Betz limit are illustrated in Figure AA.5.

Figure AA.5: Maximum theoretical power coefficients for rotating and non-rotating wakes



Neither of the analyses summarized above gives any indication as to what the blades of the rotor actually look like. For this purpose, a method called blade element momentum (BEM) theory was developed. This approach assumes that the blades incorporate an airfoil cross section. Figure AA.6 shows a typical airfoil, including some of the nomenclature.

Figure AA.6: Airfoil nomenclature



The BEM method equates the forces on the blades associated with air flowing over the airfoil with forces associated with the change in momentum of the air passing through the rotor. The starting point for this analysis is the assessment of the lift force on an airfoil. Lift is a force perpendicular to the flow. It is given by

$$\tilde{F}_L = C_L \frac{1}{2} \rho c U^2 \tag{9}$$

Where:

$\tilde{F}_L$ = force per unit length, N/m

C_L = lift coefficient, -

c = chord length (distance from leading edge to trailing edge of airfoil, m)

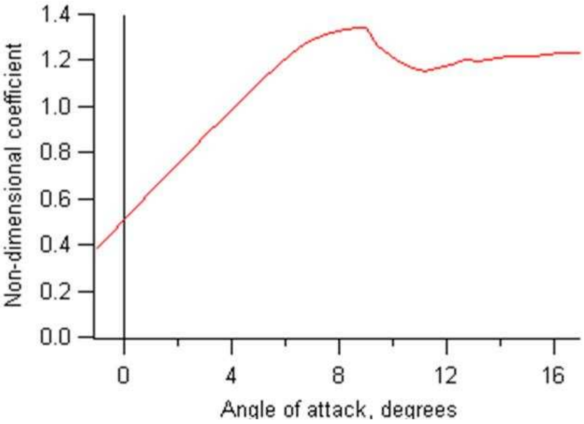
Thin airfoil theory predicts that for a very thin, ideal airfoil the lift coefficient is given by

$$C_L = 2\pi \sin\alpha \tag{11}$$

where α is the angle of attack, which is the angle between the flow and the chord line of the airfoil.

The lift coefficient for real airfoils typically includes a constant term but the slope, at least for low angles of attack, is similar to that for an ideal airfoil. For greater angles of attack (above 10–15 degrees) the lift coefficient begins to decrease, eventually approaching zero. This is known as stall. A typical lift coefficient vs. angle of attack curve is illustrated in Figure AA.7.

Figure AA.7: Typical airfoil lift vs. angle of attack



There is always some drag force associated with fluid flow. This is a force is in line with the flow. Drag force (per unit length) is given by:

$$\tilde{F}_D = C_D \frac{1}{2} \rho c U^2 \tag{12}$$

Where C_D = drag coefficient

When designing blades for a wind turbine, it is generally desired to minimize the drag to lift ratio at the design point. This generally results in a lift coefficient in the vicinity of 1.0 and a drag coefficient of approximately 0.006, although these values can differ depending on the airfoil.

Blade element momentum theory, as noted above, relates the blade shape to its performance. The following approach is used. The blade is divided into elements and the rotor is divided into annuli. Two simultaneous equations are developed: one expresses the lift and drag coefficient (and thus forces) on the blade elements as a function of airfoil data and the wind's angle of attack. The other expresses forces on the annuli as a function of the wind through the rotor, rotor characteristics, and changes in momentum. Some of the key assumptions are: (i) the forces on blade elements are determined solely by lift/drag characteristics of the airfoil, (ii) there is no flow along the blade, (iii) lift and drag force are perpendicular and parallel respectively to a “relative wind,” and (iv) forces are resolved into components perpendicular to the rotor (“thrust”) and tangential to it (“torque”).

Using BEM theory, it may be shown for an ideal rotor that the angle of relative wind, φ, as a function of tip speed ratio and radial position on the blade is given by:

$$\varphi = \left(2/3\right)\tan^{-1}\left(1/\lambda_r\right) \tag{13}$$

Similarly, the chord length is given by:

$$c = \frac{8\pi r}{BC_L}\left(1 - \cos\varphi\right) \tag{14}$$

Where B = the number of blades

There are some useful observations to be drawn out of the above equations. First of all, in the ideal case the blade will be twisted. In fact, the twist angle will differ from the angle of relative wind by the angle of attack and a reference pitch angle θ_p as follows:

$$\theta_T = \varphi - \alpha - \theta_p \tag{15}$$

It may also be noted that the twist angle will at first increase slowly when moving from the tip inward and then increase more rapidly. Second, the chord of the blade will also increase upon moving from the tip inward, at first slowly and then more rapidly. In the ideal case then, a wind turbine blade is both significantly twisted and tapered. Real blades, however, are designed with a less than optimal shape for a variety of practical reasons.

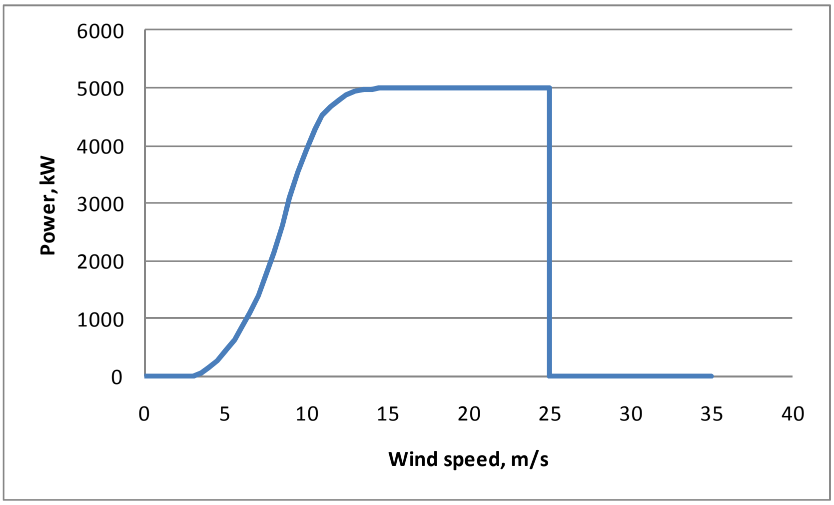
Another important observation has to do with the total area of the blades in comparison to the swept area. The ratio of the projected blade area is known as the solidity, σ. For a given angle of attack, the solidity will decrease with increasing tip speed ratio. For example, assuming a lift coefficient C_L of 1.0, the solidity of an optimum rotor designed to operate at a tip speed ratio of 2.0 is 0.43 whereas an optimum rotor designed to operate at a tip speed ratio of 6.0 would have a solidity of 0.088. It is therefore apparent that in order to keep blade material (and thus cost) to a minimum, it is desirable to design for a tip speed ratio as high as possible.

There are other considerations in selecting a design tip speed ratio for a turbine other than the solidity, however. On the one hand, higher tip speed ratios will result in gearboxes with a lower speed up ratio for a given turbine. On the other hand, the effect of drag and surface roughness of the blade surface may become more significant for a higher tip speed ratio rotor. This effect could result in decreased performance. Another concern is material strength. The total forces on the rotor are nearly the same on the rotor regardless of the solidity. Thus the stresses would be higher. A final consideration is noise. Higher tip speed ratios generally result in more noise produced by the blades.

There are numerous other considerations regarding the design of a wind turbine rotor, including tip losses, type of airfoil to be used, ease of manufacturing and transport, type of control used, selection of materials, etc. These are all outside the scope of this overview, however.

Real wind turbine rotors are designed taking into account many factors, including but not only their aerodynamic performance. In addition, the rotor must be controlled so as to generate electricity most effectively and so as to withstand continuously fluctuating forces during normal operation and extreme loads during storms. Accordingly, a wind turbine rotor does not in general operate at its own maximum power coefficient at all wind speeds. Because of this, the power output of a wind turbine is generally described by curve, known as a power curve, rather than an equation such as the one for P_{WT} which given earlier. Figure AA.8 illustrates a typical power curve. As shown there, below the cut-in speed (3 m/s in the example) no power is produced. Between cut-in and rated wind speed (14.5 m/s in this example), the power increases significantly with wind speed. Above the rated speed, the power produced is constant, regardless of the wind speed, and above the cut-out speed (25 m/s in the example), the turbine is shut down.

Figure AA.8: Typical wind turbine power curve



AA.7 Wind Turbine Mechanics and Dynamics

Earlier we discussed the aerodynamic aspects of a wind turbine, and how that related to its design, performance, and appearance. The next major consideration has to do with the turbine's survivability. This topic includes its ability to withstand the forces to which the turbine will be subjected, deflections of various components, and vibrations that may result during operations.

Issues that need to be considered include: (i) ultimate strength, (ii) relative motion of components, (iii) vibrations, (iv) loads, (v) responses, (vi) stresses, (vii) unsteady motion, resulting in fatigue, and (viii) material properties.

The types of loads that a turbine may be subjected to are as follows: static (non-rotating), steady (rotating), cyclic, transient, impulsive, stochastic, or resonance-induced. Sources of loads may include aerodynamics, gravity, dynamic interactions, or mechanical control. To understand the various loads that a wind turbine may experience, the reader may wish to review the fundamentals of statics (no motion), dynamics (motion), Newton's second law, the various rotational relations (kinematics), strength of materials (including Hooke's law and finding stresses from moments and geometry), gyroscopic forces/moments, and vibrations. Among other topics, the cantilevered beam is particularly important, since rotor blades as well as towers have similar characteristics.

Wind turbines are frequently both the source of and are subject to vibrations. Although the topic can become quite complicated, it is worthwhile to recall that the natural frequency of simple oscillating mass, *m*, and spring, with spring constant, *k*, and is given by:

$$\omega = \sqrt{k/m} \qquad (16)$$

Similarly, rotational natural frequency about an axis of rotation is given by:

$$\omega = \sqrt{k_\theta / J} \qquad (17)$$

Where k_θ is the rotational spring constant and *J* is the mass moment of inertia

A continuous body, such as a wind turbine blade, will actually have an infinite number of natural frequencies (although only the first few are important), and associated with each natural frequency will be a mode shape that characterizes it deflection. The vibration of a uniform cantilevered beam can be described relatively simply through the use of Euler’s equation (see Manwell et al., 2009). Non-uniform elements require more complex methods for their analysis.

AA.7.a Rotor Motions

There is a variety of motions that occur in the rotor that can be significant to the design or operation of the turbine. These include those in the flapwise, edgewise, and torsional directions.

Flapwise motions are those that are perpendicular to plane of the rotor, and are considered positive in the direction of the thrust. Flapwise forces are the source of the highest aerodynamic bending moments, and accordingly the most significant stresses.

Lead-lag, or edgewise, motions are in plane of rotor and are considered positive when in the direction of the torque. Fluctuating motions in this direction are reflected in the power.

Torsion refers to the twisting of blade about its long axis. Torsional moments in the blades must be accounted for in the design of pitch control mechanisms.

The most important rotor load is the thrust. This is the total force on the rotor in the direction of the wind (flapwise). It is associated with the conversion of the kinetic energy of the wind to mechanical energy. The thrust, T, (N) is given by:

$$T = C_T \frac{1}{2} \rho \pi R^2 U^2 \tag{18}$$

Where C_T is the thrust coefficient. For the ideal rotor in which the axial induction factor, a, is equal to 1/3 (corresponding to the Betz limit), it is easy to show that the thrust coefficient is equal to 8/9. For the same rotor, the thrust coefficient may be as high as 1.0, but this would not occur at $C_p = C_{p,Betz}$.

This thrust gives rise to flapwise bending moments at the root of the blade. For example, for the ideal rotor when a = 1/3, and assuming a very small hub, it may be shown that the flapwise bending moment M_β at the root of the blade would be given by:

$$M_\beta = \frac{T}{B}\frac{2}{3}R \tag{19}$$

Where B = number of blades

From the bending moment, it is straightforward to find the maximum bending stress in the blade. For example, suppose that a blade is $2t$ m thick at the root, has a symmetrical airfoil, and that the thrust force is perpendicular to the chord line. Then the bending stress would be:

$$\sigma_{\beta,\max} = \frac{M_\beta t}{I_b} \tag{20}$$

(Note that for a real blade, the asymmetry and the angles would complicate the calculation, but the principle is the same.)

Another important load is torque, Q (Nm). Torque is given by:

$$Q = C_Q \frac{1}{2} \rho \pi R^2 U^2 \tag{21}$$

Where C_Q = the torque coefficient, which also equal to C_p/λ.

Note that torque is also given by:

$$Q = P / \Omega \tag{22}$$

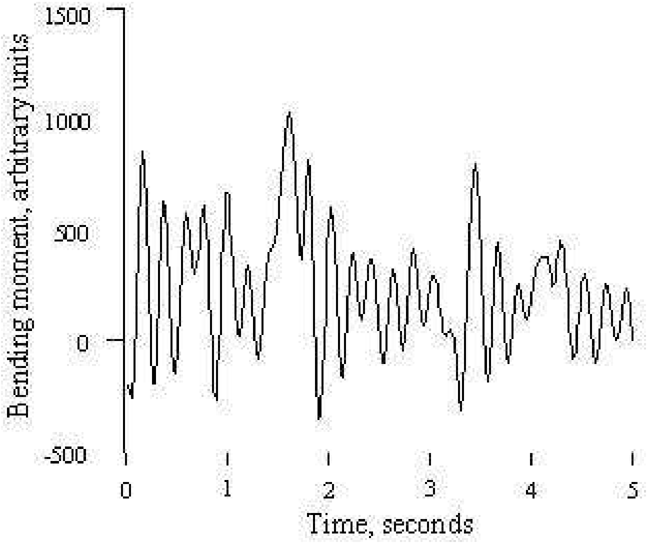
Where P = power (W)

The dynamics of a wind turbine rotor are quite complicated and do not lend themselves to simple illustrations. There is one approach, however, due to Stoddard (Eggleston and Stoddard, 1987) and summarized by (Manwell et al., 2009) which is relatively tractable, but will not be discussed here. In general, the dynamic response of wind turbine rotors must be simulated by numerical models, such as the FAST code (Jonkman, 2005) developed by the National Renewable Energy Laboratory.

AA.7.b Fatigue

Fatigue is an important phenomenon in all wind turbines. The term refers to the degradation of materials due to fluctuating stresses. Such stresses occur constantly in wind turbines due to the inherent variability of the wind, the rotation of the rotor and the yawing of the rotor nacelle assembly (RNA) to follow the wind as its direction changes. Fatigue results in shortened life of many materials and must be accounted for in the design. Figure AA.9 illustrates a typical time history of bending moment that would give rise to fluctuating stresses of similar appearance.

Figure AA.9: Typical wind turbine blade bending moment



The ability of a material to withstand stress fluctuations of various magnitudes is typically illustrated in an S-N curve. In such curves the stress level is shown on the *y* axis and is plotted against the number of cycles to failure. As is apparent from the figure above, stress fluctuations of a variety of magnitudes are likely. The effect of a number of cycles of different ranges is accounted for by the damage due to each cycle using “Miner’s Rule.” In this case, an amount of damage, *d*, due to *n* cycles, where the stress is such that *N* cycles will result in damage is found as follows:

$$d = n / N \qquad (23)$$

Miner’s Rule states that the sum of all the damage, *D*, from cycles of all magnitudes must be less than 1.0, or failure is to be expected imminently:

$$D = \sum n_i / N_i \leq 1 \qquad (24)$$

Miner’s Rule works best when the cycling is relatively simple. When cycles of varying amplitude follow each other, an algorithm called "rainflow" cycle counting” (Downing and Socie, 1982) is used.

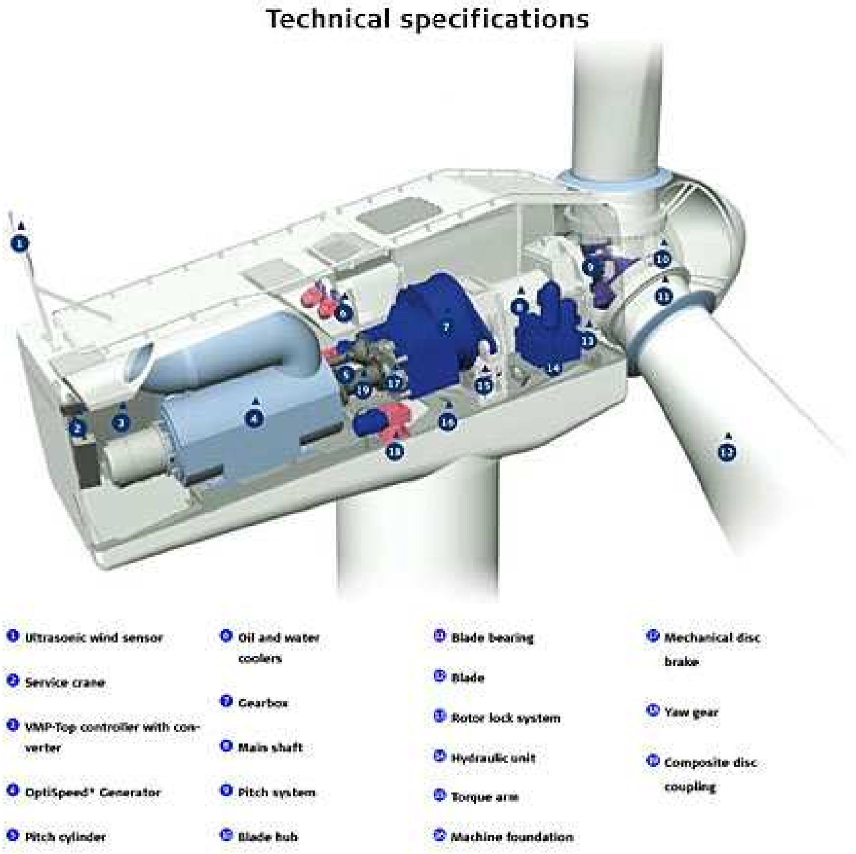
AA.8 Components of Wind Turbines

Wind turbines consist of two main subsystems, the rotor nacelle assembly and the support structure, and each of these is comprised of many components. The following provides some more description of these subsystems. More details, particularly on the rotor nacelle assembly may be found in (Manwell et al., 2009).

AA.8.a Rotor Nacelle Assembly

The rotor nacelle assembly (RNA) includes the majority of the components associated with the conversion of the kinetic energy of the wind into electrical energy. There are two major component groupings in the RNA as well as a number of ancillary components. The main groupings are the rotor and the drive train. The rotor includes the blades, the hub, and pitch control components. The drive train includes shafts, bearings, gearbox (if any), couplings, mechanical brake, and generator. Other components include the bedplate, yaw bearing and yaw drive, oil cooling system, climate control, other electrical components, and parts of the control system. An example of a typical rotor nacelle assembly is illustrated in Figure AA.10.

Figure AA.10: Typical Rotor Nacelle Assembly



(From Vestas http://re.emsd.gov.hk/english/wind/large/large_to.html)

AA.8.b Rotor

The primary components of the rotor are the blades. At the present time, most wind turbines have three blades, and they are oriented so as to operate upwind of the tower. It is to be expected that in the future some wind turbines, particularly those intended for use offshore, will have two blades and will be oriented downwind of the tower, however. For a variety of reasons (including that downwind turbines tend to be noisier) it is less likely that they will be used on land, particularly in populated areas.

The general shape of the blades is chosen in accordance with the principles discussed previously. The other major factor is the required strength of the blades. For this reason, it is often the case that thicker airfoils are used nearer the root than are used closer to the tip. Blades for most modern wind turbines are constructed of composites. The laminates are primarily fiberglass with some carbon fiber for additional strength. The binders are polyester or epoxy.

At the root of the blades the composite material is attached to a steel root, which can then be subsequently bolted to the hub. Most utility scale wind turbines at present include blade pitch control, so there is a mechanism present at the interface of the hub and the blades that will both secure the blades and facilitate their rotation about their long axis.

The hub of the wind turbine rotor is constructed from steel. It is designed so as to attach to the main shaft of the drive train as well as to connect with the blades.

AA.8.c Drive train

The drive train consists of a number of components, including shafts, couplings, a gearbox (usually), a generator, and a brake.

AA.8.d Shafts

The main shaft of the drive train is designed to transmit the torque from the rotor to the gearbox (if there is one) or directly to the generator if there is no gearbox. This shaft may also be required to carry some or all of the weight of the rotor. The applied torque will vary with the amount of power being produced, but in general it is given by the power divided by the rotational speed. As discussed previously, a primary consideration in the aerodynamic design of a wind turbine rotor is the tip speed ratio. A typical design tip speed ratio is 7. Consider a wind turbine with a diameter of 80 m, designed for most efficient operation at a wind speed 12 m/s. The rotational speed of the rotor and thus the main shaft under these conditions would be 20 rpm.

AA.8.e Gearbox

Wind turbines are intended to generate electricity, but most conventional generators are designed to turn at higher speeds than do wind turbine rotors (see below). Therefore, a gearbox is commonly used to increase the speed of the shaft that drives the generator relative to that of the main shaft. Gearboxes consist of a housing, gears, bearings, multiple shafts, seals, and lubricants. Gearboxes for wind turbines are typically either of the parallel shaft or planetary type. Frequently a gearbox incorporates multiple stages, since the maximum allowed ratio per stage is usually well under 10:1. There are trade-offs in the selection of gearbox. Parallel shaft gearboxes are generally less expensive than planetary ones but they are also heavier. Gearboxes are generally quite efficient. Thus the power out is very nearly equal to the power in. The torque in the shafts is then equal to the power divided by the speed of the shaft.

AA.8.f Brake

Nearly all wind turbines incorporate a mechanical brake somewhere on the drive train. This brake is normally designed to stop the rotor under all foreseeable conditions, although in some cases it might only serve as a parking brake for the rotor. Mechanical brakes on utility scale wind turbines are mostly of the caliper/disc type although other types are possible. Brakes may be placed on either the low speed or the high speed side of the gearbox. The advantage of placing it on the high speed side is that less braking torque is required to stop the rotor. On the other hand, the braking torque must then pass through the gearbox, possibly leading to premature failure of the gearbox. In either case, the brake must be designed to absorb all of the rotational energy in the rotor, which is converted into heat as the rotor stops.

AA.8.g Generator

Electrical generators operate via the rotation of a coil of wire in a magnetic field. The magnetic field is created by one or more pairs of magnetic poles situated opposite each other across the axis of rotation. The magnetic field may be created either by electromagnets (as in conventional synchronous generators), by induction in the rotor (as in induction generators,) or with permanent magnets. In alternating current systems the number of pairs of poles and the grid frequency determine the nominal operating speed of the generator. For example, in a 60 Hz AC system, such as the United States, a generator with two pairs of poles would have a nominal operating speed of 1800 rpm. In most AC generators, the field rotates and while the current is generated in a stationary armature (the stator).

The majority of utility scale wind turbines today use wound rotor induction generators (WRIG). This type of generator can function over a relatively wide range of speeds (on the order of 2:1). Wound rotor induction generators are employed together with a power electronic converter in the rotor circuit. In such an arrangement approximately 2/3 of the power is produced on the stator in the usual way. The other third of the power is produced on the rotor and converted to AC of the correct frequency by the power electronic converter. In this configuration the WRIG is often referred to as a doubly fed induction generator (DFIG).

A number of wind turbines use permanent magnet generators. Such generators often have multiple pole pairs as well. This can allow the generator to have the same nominal speed as the wind turbine rotor so the main shaft can be connected directly to the generator without the use of a gearbox. Most permanent magnet generators are designed to operate together with power electronic converters. These converters facilitate variable speed operation of the turbine, while ensuring that the electricity that is produced is of constant frequency and compatible with the electrical grid to which the turbine is connected.

AA.8.h Bedplate

The bedplate is a steel frame to which components of the drive train and other components of the RNA are attached. It ensures that all the components are properly aligned.

AA.8.i Yaw System

Most wind turbines today include a yaw system. This system facilitates orienting the RNA into the wind as the wind direction changes. First of all, there is a slewing bearing that connects the top of the tower to the RNA, allowing the latter to rotate with respect to the former. Also attached to the top of the tower, and often to the outside perimeter of the slewing bearing, is a large diameter bull gear. A yaw motor connected to a smaller gear is attached to the bedplate. When the yaw motor is energized, the small gear engages the bull gear, causing the RNA to move relative to the tower. A yaw controller ensures that the motion is in the proper direction and that it continues until the RNA is aligned with the wind. A yaw brake holds the RNA fixed in position until the yaw controller commands a new orientation.

AA.8.j Control System

A wind turbine will have a control system that ensures the proper operation of the turbine at all times. The control system has two main functions: supervisory control and dynamic control. The supervisory control continuously monitors the external conditions and the operating parameters of the turbine, and starts it up or shuts it down as necessary. The dynamic control system ensures smooth operation of various controllable components, such the pitch of the blades or the electrical torque of the generator. The control system may also be integrated with or at least be in communication with a condition monitoring system that watches over the condition of various key components.

AA.8.k Support Structure

The support structure of a wind turbine is any part of the turbine that is below the main bearing. The support structure for land-based wind turbines may be conceptually divided into two main parts: the tower and the foundation. The tower of a wind turbine is normally constructed of tapered steel tubes. The tubes are bolted together on site to form a single structure of the desired height. The foundation of a wind turbine is the part of the support structure, which is in contact with the ground. Foundations are typically constructed of reinforced concrete. When turbines are installed on rock, the foundations may be attached to the rock with rods, which are grouted into predrilled holes.

AA.8.l Materials for Wind Turbines

The primary types of materials used in the various components of wind turbines are steel, copper, composites, and concrete.

AA.9 Installation

Installation of wind turbines may be a significant undertaking. It involves the following:

- Complete assessment of site conditions
- Detailed preparing for the installation
- Constructing the foundation
- Delivering the components to the site
- Assembling the components into sub-assemblies
- Lifting the sub-assemblies into place with a crane
- Installing the electrical equipment
- Final testing

More details may be found in (Manwell et al., 2009).

AA.10 Energy Production

The purpose of wind turbines is to produce energy. Energy production is usually considered annually. The amount of energy that a wind turbine will produce in a year, $E_{y,}$ is a function of the wind resource at the site where it is installed and the power curve of the wind turbine. Estimates are usually done by calculating the expected energy that will be produced every hour of a representative year and then summing the energy from all of those hours as shown below:

$$E_y = \sum_{i=1}^{8760} P_{WT}(U_i)\Delta t \qquad (25)$$

Where U_i is the wind speed in the i^{th} hour of the year, $P_{WT}(U_i)$ is the average power (based on the power curve) during the i^{th} hour and Δt is the length of the time period of interest (here, one hr). The units of energy are Wh, but the amount of energy production is frequently expressed in either kWh or MWh for the sake of convenience.

It is sometimes cumbersome to characterize the performance of a wind turbine by its actual energy production. Accordingly, a normalized term known as the capacity factor, *CF*, is used. This is the given by the actual energy that is produced (or estimated to be produced) divided by the amount of energy that would be produced if the turbine were running at is rated output, P_R, for the entire year. It is found from the following equation:

$$CF = \frac{E_y}{8760 P_R} \qquad (26)$$

AA.11 Unsteady Aspects of Wind Turbine Operation

There are a number of unsteady aspects of wind turbine operation that are significant to the discussion of public reaction to wind turbines. These in particular include the variations in the wind field that can change the nature of the sound emitted from the rotor during operation. These unsteady effects include the following:

1. Wind shear – Wind shear refers to the variation of wind speed across some spatial dimension. Wind shear is most commonly thought of as a vertical phenomenon, that is to say, the increase of wind speed with height. Wind shear can also occur laterally across the rotor under some circumstances. Vertical wind shear is often modeled by a power law as discussed earlier. There are some situations, however, in which such a model is not applicable. One example has to with highly stable atmosphere, such that the wind near the ground is relatively light, but at the height of the rotor the wind is high enough that turbine may be operating. Under such conditions there may be sound emanating from the rotor, but relatively little wind induced sound near the ground to mask that from the rotor. Wind shear may also result in a cyclically varying aspect to the sound produced by the blades as they rotate. This occurs due to the changing magnitude and direction of the relative wind as the blades pass through zones of different wind speed.
2. Tower shadow or blockage – The wind flow near the tower is inevitably somewhat different from where there is no tower. The effect is much more pronounced on wind turbines with downwind rotors, but it still occurs with up-wind rotors. This tower effect can result in a distinct change in sound once per revolution of each blade.

3. Turbulence – Turbulence refers to changes in magnitude and direction of the wind at varying time scales and length scales. The presence of turbulence can affect the nature of the sound.
4. Changes in wind direction – Wind turbines are designed to yaw in response to changes in wind direction. The yawing process takes a finite amount of time and during that time the wind impinging on the rotor will do so at a different direction than it will when the yawing process is complete. Sound produced during the yawing process may have a somewhat different character than after it is complete.
5. Stall – Under some conditions part or all of the airfoils on the blades may be in stall. That is, the angle of relative wind is high enough that the airfoil begins to lose lift. Additional turbulence may also be generated. Again, the nature of the sound produced by the rotor may be different than during an unstalled state. It may also be noted that some turbines intentionally take advantage of stall to limit power in high winds. Under such conditions there may also be a change in sound in comparison to normal operation.

AA.11.a Periodicity of Unsteady Aspects of Wind Turbine Operation

Due to the rotation of the rotor and the nature of the wind, there tend to be certain features of the turbine's operation that are periodic in nature. The most dominant of these have frequencies associated with the rotational speed of the rotor and the blade passage frequency, which is simply the rotational speed times the number of blades. For example, the dominant frequencies in a 3-blade wind turbine rotating at 20 rpm would be 0.33 Hz and 1 Hz. Other significant frequencies may be the first few harmonics of the rotational frequency and blade passage frequency.

AA.12 Wind Turbines and Avoided Pollutants

Wind turbines have a positive impact on human health via avoiding emission of pollutants that would result if the electricity that they generate were produced instead by other generators. While the average emissions of various pollutants per MWh produced from conventional generators is relatively easy to estimate, it is harder to estimate the actual impact of wind turbine generation. This is because the electricity distributed by the electrical grid is produced by different types of generators, and the operation of these generators will be affected differently as a result of the supply of part of the total electrical demand by the wind turbines.

In general, electricity in any large utility network comes from three types of generators: base load, intermediate load, and peaking plants. The fuel or energy source supplying these generators is likely to be coal, fuel oil, natural gas, uranium (nuclear plants), or water (hydroelectric plants). Base load plants are typically coal fired or nuclear plants. Intermediate load plants often use fuel oil or natural gas. Peaking plants are normally natural gas or hydroelectric. There are a considerable number of plants that may be operating at any given time. Which plants are actually operating is determined by the system operator in accordance with what the near term forecasted load is expected to be and the estimated (bid) cost per MWh from all the plant operators in the system. For thermal plants the bid cost is close to that projected fuel cost/MWh. This in turn is found from heat rate of the fuel (kg/MWh) for the plant in question times the unit cost of the fuel ($/kg). Less efficient plants or those with higher unit fuel costs tend to have relatively high bid costs. (Note on the other hand, that wind turbines would have bid costs of zero, since they do not use fuel.)

If a large number of wind turbines are operating such that they are contributing a significant amount of electricity to the total load, the mix of generators may well be different than it would be if the turbines were not present. If only a small number of wind turbines are present, then the mix of generators may not change. However, certain of the plants would be curtailed so as to produce less energy and thus consume less fuel. The emissions of pollutants from all the operating plants could be calculated and so could the projected emissions that would have resulted if the wind turbines were not present. The difference in amount of pollutants produced could then be assigned to the wind turbine as the avoided emissions.

To do such an analysis properly involves estimating the actual impact of wind turbine generation on the mix of generators and the operating level of those generators for every hour of the year. This is a non-trivial exercise, but it has been done for an offshore wind farm that was proposed for the town of Hull, MA. That project was to have included four 3.6 MW turbines, for a total capacity of 14.4 MW. The pollutants considered in the study were CO_2, $NO_{X,}$ and SO_X. The results of that study are described in detail in (Rached, 2008). The results of that study are summarized in Table AA.1. The results in the table are normalized for a 1 MW (rated) wind turbine and use the medium estimated wind speed for the site. (Note under the assumptions of Rached’s study, a one MW (rated) wind turbine in the medium wind speed scenario at the site would generate 2,580 MWh/yr).

Table AA.1:

Avoided emissions of pollutants for 14.4 MW wind project (based on Rached, 2008)

CO_2 (kg/MWyr)	SO_X (kg/MWyr)	NO_X (kg/MWyr)
1,970,000	3,480	1,490

A simpler but less accurate way to estimate the avoided emissions is to use the marginal rates for pollutants as specified by the Massachusetts Greenhouse Gas policy (MEPA, 2007). Applying this method Rached calculated avoided emissions per MW (rated) for the three pollutants for one year of 1,320,000 kg CO_2, 2,080 kg of SO_2, and 701 kg of NO_x.

In the analysis summarized above the majority of the avoidance of pollutant production would be due to reduced consumption of natural gas. If a larger fraction of Massachusetts' energy were to be produced by wind energy, there could be significant reductions of the consumption of fuel oil and coal as well. This should result in larger amounts of avoided pollution per unit of wind turbine production

Appendix B

Wind Turbines – Shadow Flicker

AB.1 Shadow Flicker and Flashing

Shadow flicker occurs when the moving blades of a wind turbine rotor cast moving shadows that cause a flickering effect. This flicker could annoy people living close to the turbine. Similarly, it is possible for sunlight to be reflected from gloss-surfaced turbine blades and cause a "flashing" effect. This phenomenon will occur during a limited amount of time in a year, depending on the altitude of the sun, α_S; the height of the turbine, *H*, the radius of the rotor, *R*, and the height, direction and distance to the viewing point. At any given time the maximum distance from a turbine that a flickering shadow will extend is given by:

$$x_{shadow,\max} = \left(H + R - h_{view}\right) / \tan\left(\alpha_s\right) \qquad (27)$$

Where h_{view} is the height of the viewing point.

The solar altitude depends on the latitude, the day of the year, and the time as given in the following equations (Duffie and Beckman, 2006)

$$\alpha_s = 90° - \cos^{-1}\left[\cos(\delta)\cos(\phi)\cos(\omega) + \sin(\delta)\sin(\phi)\right] \qquad (28)$$

Where δ = declination of the earth's axis, ø = latitude and ω = the hour angle

The declination is found from the following equation:

$$\delta = 23.45\sin(360(284 + n)/365) \qquad (29)$$

Where n = day of the year

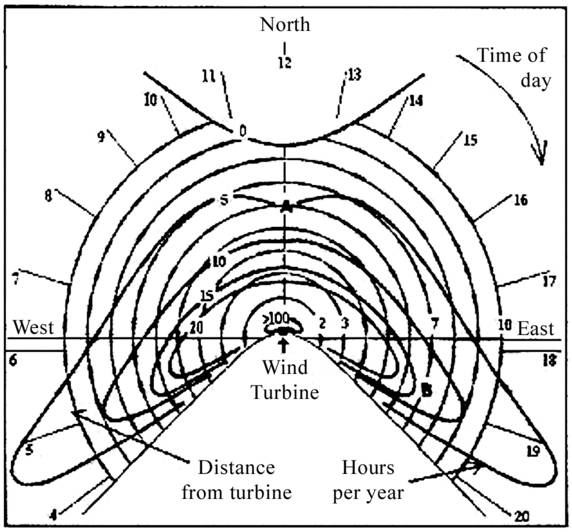
The hour angle is found from the hours from noon (solar time, negative before noon, positive after noon), divided by 15 to convert to degrees.

Another relevant angle is the solar azimuth. This indicates the angle of the sun with respect to certain reference direction (usually north) at a particular time. For example, the sun is always in the south at solar noon, so its azimuth is 180° at that time. The solar azimuth is important since it determines the angle of the wind turbine's shadow with respect to the tower. See Duffie and Beckman (2006) for details on calculating the solar azimuth.

For example, consider a location that has a latitude of 43°. Assume that the day is March 1 (day 60) and the time is 3:00 in the afternoon. Also assume that the turbine has a tower height of 80 m and a radius of 30 m and that the viewing height is 2 m. The declination is -8.3°, the solar altitude is 24.4°, and the solar azimuth is 50.2° W of S. The maximum extent of the shadow is 238 m from the turbine. The angle of the shadow is 50.2° E of N.

Sites are typically characterized by charts such the one illustrated in Figure AB.1 for a location in Denmark (EWEA, 2004). The chart gives the number of hours per year of flicker shadow as a function of direction and distance (measured in units of hub height). In the example shown, two viewing points are considered. One of them (A) is directly to the north of turbine at a distance of 6 times the hub height. The other (B) is located to the south east at a distance of 7 times the hub height. The figure shows that the first viewing point will experience shadow flicker from the turbine for 5 hours per year. The second point will experience flicker for about 12 hours per year.

Figure AB.1: Diagram of shadow flicker calculation (EWEA, 2004)



A, B are viewing points
Note that the equations above assume a clear sky and the absence of rain, clouds, etc.

AB.2 Mitigation Possibilities

Most modern wind turbines allow for real-time control of turbine operation by computer in order to shut down during high shadow flicker times, if necessary. In addition, computer programs can allow for pre-planning of siting location ahead of time to know what a project specific impact will be in terms of shadow flicker when planning a wind turbine project (as discussed in the previous paragraph). This planning can be site-specific in order to avoid potential problems with specific sites based on geographical location or weather patterns.

In terms of safe distances to reduce shadow flicker, these are often project-specific because it depends on whether there are residences or roadways present and what the geographic layout is. This could be particularly important in areas with more forestry and existing shadow, which could reduce nuisance from turbine produced shadow flicker or whether it is an otherwise open land area such as farmland that would be more susceptible to the annoyance of shadow flicker. A general estimate for modeling a shadow flicker risk zone includes 10 times the rotor diameter such that a 90-meter diameter would be equivalent to a 900-meter impact area. However, only certain portions of this zone are actually likely to experience shadow flicker for a significant amount of time. Other modeling considerations include when at least 20% of the sun is covered by the blade and whether to include the blade width in estimates as well. In terms of distance, 2,000 meters is the WindPro computer program default distance (NEWEEP, 2011) for calculations of wind turbine produced shadow flicker. Finally, due to atmospheric effects, 1400 m is the maximum distance from a turbine within which shadow flicker is likely to be significant.

In terms of existing regulations regarding shadow flicker rates, there are no current shadow flicker regulations in Massachusetts (or many other New England states, but there are statewide and local guidelines that have been implemented. These guidelines were provided by the Department of Energy Resources in March 2009 and state that, “wind turbines shall be sited in a manner that minimizes shadowing or flicker impacts” and, “the applicant has the burden of proving that this effect does not have significant adverse impact on neighboring or adjacent uses.” Local Massachusetts regulations include the Worcester, MA zoning ordinance, which requires, “The facility owner and operator shall make reasonable efforts to minimize shadow flicker to any occupied building on a non-participating landowner’s property.” Also, a shadow flicker assessment report is required as is a plan showing the “area of estimated wind turbine shadow flicker.” Similarly, the Newburyport, MA regulations require that wind turbines do not result in significant shadow or flicker impacts and an analysis is required for planned projects (NEWEEP, 2011).

The Maine model wind energy facility ordinance states that wind turbines should, “avoid unreasonable adverse shadow flicker effect at any occupied building located on a non-participating landowner's property." They do not state any specific limit to shadow flicker other than these guidelines. However, the New Hampshire Model Small Wind Energy Systems Ordinance states that wind turbines, "shall be sited in a manner that does not result in significant shadow flicker impacts…significant shadow flicker is defined as more than 30 hours per year on abutting occupied buildings." Similar to Maine, several states in the US have adopted the German model of 30 hours per year of allowed shadow flicker that was primarily based on the government-sponsored study summarized above. However, other states or localities including Hutchinson, Minnesota have enacted stricter guidelines including no shadow flicker to be allowed at an existing residential structure, and up to 30 hours per year of shadow flicker allowed on roadways or residentially zoned properties and a computer analysis is required for project approval (NEWEEP, 2011).

In addition, computer programs such as WindPro are also recommended by most states and localities for use in all new planned installations to reduce this potential nuisance of shadow flicker on residential properties or potential health hazards to drivers on busy highways or roadways.

Appendix C

Wind Turbines – Ice Throw

AC.1 Ice Falling or Thrown from Wind Turbines

Under certain weather conditions ice may form on the surface of wind turbine blades. Normally, wind turbines intended for use in locations where ice may form are designed to shut down when there is a significant amount of ice on the blades. The means to prevent operation when ice is present may include ice sensor and vibration sensors. Ice sensors are used on most wind turbines in cold climates. Vibration sensors are used on nearly all wind turbines. They would cause the turbine to shut down, for example, if ice buildup on the blades resulted in an imbalance of the rotor and hence detectable vibrations in the structure.

Ice built up on blades normally falls off while the turbine is stationary. If that occurs during high winds, the ice could be blown by the wind some distance from the tower. In addition, it is conceivable that ice could be thrown from a moving wind turbine blade under some circumstances, although that would most likely occur only during startup (while the rotational speed is still relatively low) or as a result of the failure of the control system. It is therefore worth considering what the maximum plausible distance that a piece of ice could land from the turbine under two “worst case” circumstances: 1) ice falls from a stopped turbine during very high winds, and 2) ice is suddenly released from a blade when the rotor is rotating at its normal operating speed.

In both cases, the distance that the ice may travel is governed by Newton’s laws and the principles of fluid mechanics. Calculations are quite simple when the effect of the air (and the wind) is ignored. For example, in that case if a piece of ice falls from a turbine, it will land directly below where it is released. The situation is a little more complex, but still readily solvable if the piece of ice is moving when it is released. For example, suppose that the ice is initially on the tip of a blade, and the blade is pointing vertically upward. Once the ice is released it will continue moving horizontally at the speed it had when it was still attached to the blade. But it will also begin to fall towards the ground, so the piece of ice will have two components of velocity until the ice hits the ground. The time t_g (s) it takes for the ice to reach the ground (assuming a horizontal surface) is $t_g = \sqrt{2h/g}$ where h = height (m) at which the ice is released and g = acceleration of gravity (9.81 m/s^2). The distance x (m) that the ice would travel is $x = t_g \Omega R$ where Ω is the rotational speed of the rotor (rad/s) and R is the length of the blade (m).

Such an analysis is overly simplified, however. It would underestimate the distance that the ice would travel if it fell from a stationary turbine in a high wind, and it would overestimate the distance that the ice would travel if it were suddenly released from a moving blade. It is necessary to consider the effect of the air and the force that it will impart upon the falling ice. For motion in the vertical (z) direction the equation of motion is the following:

$$F_z = ma_z \tag{30}$$

where F_z is the net force (N), m is the mass (kg), and a_z is the acceleration (m/s^2). The force includes two main components. One is the weight, W (N). It is due to gravity and acts in the negative z direction. The other one is due to the drag of the air and it acts opposite to the direction of the velocity. It is found from:

$$F_D = \frac{1}{2} C_D \rho A V_z^2 \tag{31}$$

where ρ is the density of air (1.225 kg/m^2 under standard conditions), A is the projected area (m^2) of the piece of ice, C_D is the drag coefficient of the ice and V_z is the velocity of the ice (m/s) in the z direction.

Acceleration is the derivative of the velocity, so we can rewrite the equation of motion for the vertical direction as follows:

$$\frac{dV_z}{dt} = \left(-W - sign(V_z) \frac{1}{2} C_D \rho A V_z^2 \right) / m \tag{32}$$

Where *sign* (…) indicates the direction of motion along the z axis. For the general case, the piece of ice may leave the blade with initial speed ΩR at an arbitrary angle θ with respect to the horizontal. Accordingly, there will be two components of the velocity, one in the z direction (as before) V_z, the other in the x direction, V_x. This assumes that the x axis is horizontal, is also in the plane of the rotor, and is positive in the direction of the tip of the blade at its apogee.

These velocities are initially:

$$V_{z,0} = \Omega R \sin(\theta) \tag{33}$$

$$V_{x,0} = \Omega R \cos(\theta) \tag{34}$$

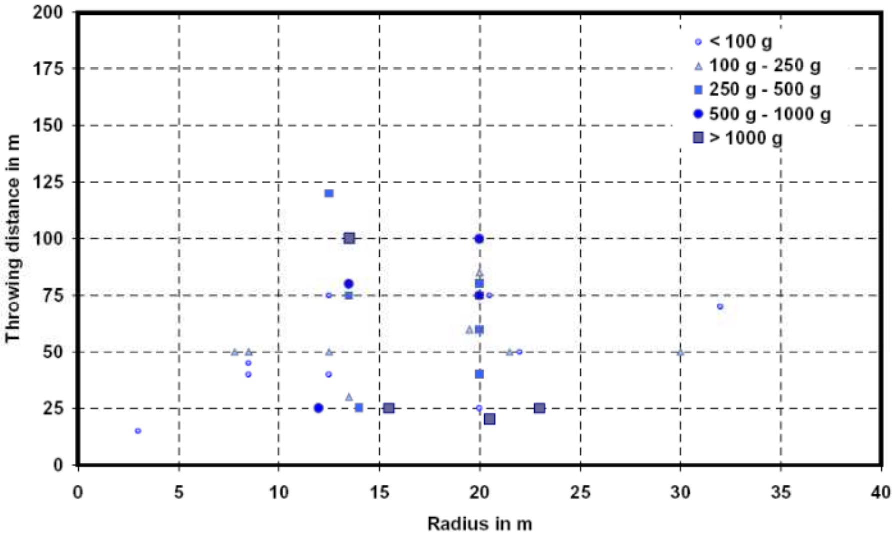
The equation of motion for the *x* direction is:

$$\frac{dV_x}{dt} = \left(-sign(V_z) \frac{1}{2} C_D \rho A V_x^2 \right) / m \tag{35}$$

The above equations are a bit difficult to solve analytically, but they can be solved numerically fairly easily. Similar equations may also be developed for the case of a particle of ice falling from a stationary turbine.

Some data from actual ice throw has been compiled by Seifert et al. (2003). Figure AC.1, taken from that report is shown below.

Figure AC.1: Observed throwing distance of ice (from Seifert et al., 2003)



As may be seen in the figure, the maximum distance that ice was observed to fall from a turbine with a diameter of 20 m during operation was approximately 100 m. Based on the observed data, Seifert et al. suggest the following simplified formula for the maximum throwing distance:

$$x_{\max,throw} = 1.5\left(2R + H\right) \tag{36}$$

Where $x_{max,throw}$ = maximum throwing distance (m), R = rotor diameter (m) and H = hub height (m).

By way of illustration, Equation 36 was used to predict the maximum throwing distance of a piece of ice from a turbine with a rotor radius of 20 m installed on a tower 50 m high. That distance was 135 m. The theoretical equations given previously were also used to calculate throwing distance. The following assumptions were made: spherically shaped piece of ice, drag coefficient of 1.2, air density of 1.225 kg/m^3, ice density of 700 kg/m^3, rotor speed of 40 rpm (corresponding to a tip speed ratio of 7 at a wind speed of 12 m/s), angle of release of 45°, and instantaneous release of the ice. The equations predict a maximum throwing distance of 226 m or somewhat less than twice that predicted from the empirical equation. The difference is deemed to be reasonable, especially considering the idealized shape of the particle. Real pieces of ice would actually be highly non-spherical in shape and experience considerably more drag. It may also be noted that it was reported in Cattin et al. (2007) that ice did not fall as far from a wind turbine in the Swiss Alps as would be predicted from Equation 36. In that case the maximum observed distance from a turbine with radius of 20 m and a tower height of 50 m was 92 m. As noted above, Equation 36 predicts 135 m.

Seifert et al. also considered data regarding ice thrown from stationary turbines. Based on the available data they proposed a simple equation for predicted ice fall. That equation is

$$x_{\max,\,fall} = U\left(R + H\right)/15 \tag{37}$$

Where U = wind speed at hub height in m/s, $x_{max,fall}$ = maximum falling distance (m), R = rotor radius (m), H = hub height (m).

Using Equation 37, the predicted maximum distance for a turbine with a radius of 20 m, a tower height of 50 m, and a wind speed of 20 m/s is 120 m. By way of comparison, the fall distance was predicted from the theoretical equations given above for the same situation. The results are highly dependent on the size of the piece of ice and hence the surface to volume ratio. To take one example, a piece of ice that was assumed to be spherical and to have a weight of 10 g would land 110 m from the tower. In the examples discussed by Seifert et al., all the pieces of ice landed less than 100 m from the tower.

AC.2 Summary of Ice Throw Discussion

As noted above, there are two plausible scenarios in which ice may fall from a wind turbine and may land at some distance from the tower. In the first scenario, ice that falls from a stationary turbine is blown some distance from the tower. In the second scenario, ice is thrown from the blade of an operating turbine during a failure of the control system. In the first case, ice may land 100 m or more from the tower in high winds, depending on the wind speed, the height from which the ice falls, and the dimensions of the ice. In the second case, the ice could land even further from the turbine. Just how far would depend on the actual speed of the rotor when the ice was shed, the height of the tower, the length of the blade, the angular position of the blade when the ice was released, and the size and shape of the ice. In general, it appears that ice is unlikely to land farther from the turbine than its maximum vertical extent (tower height plus the radius.)

Appendix D

Wind Turbine – Noise Introduction

Noise is defined simply as unwanted sound. Sound is defined as the sensation produced by stimulation of the organs of hearing by vibrations transmitted through the air or other medium. In air, the transmission is due to a repeating cycle of compressed and expanded air. The frequency of the sound is the number of times per second, Hertz (Hz), that the cycle repeats. Sound at a single frequency is called a tone while sound that is a combination of many frequencies is called broadband.

The human ear is capable of responding over a frequency range from approximately 20 Hz to 20 kHz (Hz: Hertz = 1 cycle/second; Middle C on a piano is a frequency of 262 Hz).

AD.1 Sound Pressure Level

Sound is characterized by both its frequency and its amplitude. Sound pressure is measured in micro Pascals (µPa). Because sound pressure can vary over a wide range of magnitudes a logarithmic scale is used to convert micro Pascals to decibels. Thus sound pressure level (SPL) is defined by $\mathrm{SPL} = 10 \log_{10} [p^2/p^2_{\mathrm{ref}}] = 20 \log_{10}(p/p_{\mathrm{ref}})$ with the resulting number having the units of decibels (dB). The reference pressure p_{ref} for airborne sound is 20×10^{-6} Pa (i.e., 20µPa or 20 micro Pascals). This means that SPL of 0 dB corresponds to a sound wave with amplitude 20µPa. 140 dB is considered the threshold of pain and corresponds to 20,000,000 µPa. Doubling the amplitude of the sound wave increases the SPL by 6 dB.

Therefore, a 40µPa amplitude sound wave would have an SPL of about 6 dB.

When it is stated that there is a large frequency range over which humans can hear, it is also noted that the ear does not hear each frequency similarly. In fact, there is a frequency-dependent threshold of hearing (lower limit) and threshold of pain (higher limit). Experiments have been performed to determine these thresholds. The threshold of hearing curves show that one can hear a tone at 3 kHz (3000 Hz) with an SPL < 0 dB while at 100 Hz one does not hear the tone until its SPL is about 30 dB. Curves showing the thresholds can be easily found in textbooks and online (one online example is at

http://www.santafevisions.com/csf/html/lectures/007_hearing_II.htm). Experiments have also been conducted to determine equal loudness level contours. These contours indicate when two tones of dissimilar frequencies appear to be equally loud.

Some characteristics of human response to sound include:

- Changes in sound level <1 dB cannot be perceived
- Doubling the magnitude of the acoustic pressure leads to a 6 dB increase in SPL
- A 5 dB SPL change will result in a noticeable community response
- A 10 dB SPL change is subjectively heard as an approximate doubling in loudness

AD.2 Frequency Bands

Most sounds in our environment contain multiple frequencies and are variable in that successive identical experiments cannot result in the exact same plot or tabulation of pressure vs. time. Therefore, it is common to use averages that measure approximately the amplitude of the sound and its frequency content. Common averaging methods rely on the principle of octaves, such as 1/10, 1/3, and single octave bands. This means that the entire frequency range is broken into chunks such that the relation between the starting and ending frequencies of each chunk, f_1 and f_2 respectfully, are related by $f_2 = 2^{1/N}f_1$ where N = 1 for a single octave band and 3 for a 1/3 octave band. Because the bands can be constructed based on any starting frequency, a standardized set of bands have been specified. They are usually described by the center frequency of each band. The standard octave-bands are given in Table AD.1 (measured in Hz):

Table AD.1:

Octave bands. Values given in Hz.

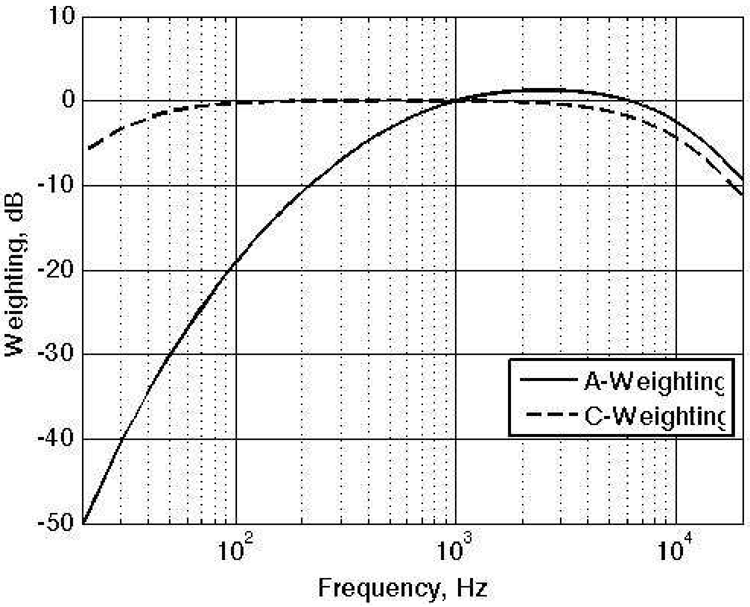
Center Frequency	Lower Band limit	Upper Band Limit
16	11	22
31.5	22	44
63	44	88
125	88	177
250	177	355
500	355	710
1000	710	1420
2000	1420	2840
4000	2840	5680
8000	5680	11360
16000	11360	22720

A similar set of bands can be written for the 1/3 octaves. For each octave band there are 3-1/3 octave bands. Many text and online resources specify the 1/3 octave bands such as (http://www.engineeringtoolbox.com/octave-bands-frequency-limits-d_1602.html). The 1/10 octave band is a narrow-band filter and is used when the sound contains important tones.

AD.3 Weightings

Noise data are often presented as 1/3 octave band measurements. Again, this means that the sound in each frequency band has been averaged over that frequency range. Noise levels are also often reported as weighted values. The most common weighting is A weighting. It was originally intended to be such that sounds of different frequencies giving the same decibel reading with A weighting would be equally loud. The weighting of the octave band centered at 31.5 Hz requires one to subtract 39.4 dB from the actual SPL. The octave bands with centers from 1000 to 8000 where human hearing is most sensitive are corrected by only about +/- 1 dB. When considered together with the threshold of hearing, it is clear that the A-weighting is most applicable for sounds of small amplitude. C-weighting on the other hand subtracts only a few dB from the very highest and very lowest frequency bands. It is therefore more applicable for higher levels of sound. The figure below shows these two weightings. When weighted, the sound pressure level is reported as dBA or dBC respectively.

Figure AD.1: Weighting values for reporting sound pressure levels



.

Noise levels change several times per day. To account for these differences other environmental noise measures are often used as shown in Table AD1.

Table AD 2:

A set of visual examples for these measures can be found at (*http://www.epd.gov.hk/epd/noise_education/web/ENG_EPD_HTML/m2/types_3.html*)

Indicator	**Meaning**
L_{max}	The maximum A-weighted sound level measured
L_{10}, L_{50}, L_{90}	The A-weighted sound level that is exceeded n%, of the time, where n is 10, 50, and 90 respectively. During the measurement period L_{90} is generally taken as the background sound level.
L_{eq}	Equivalent sound level. The average A-weighted sound pressure level, which gives the same total energy as the varying sound level during the measurement period of time.
Ldn	Day-night level. The average A-weighted sound level during a 24-hour day after addition of 10 dB to levels measured in the night between 10 p.m. and 7 a.m.

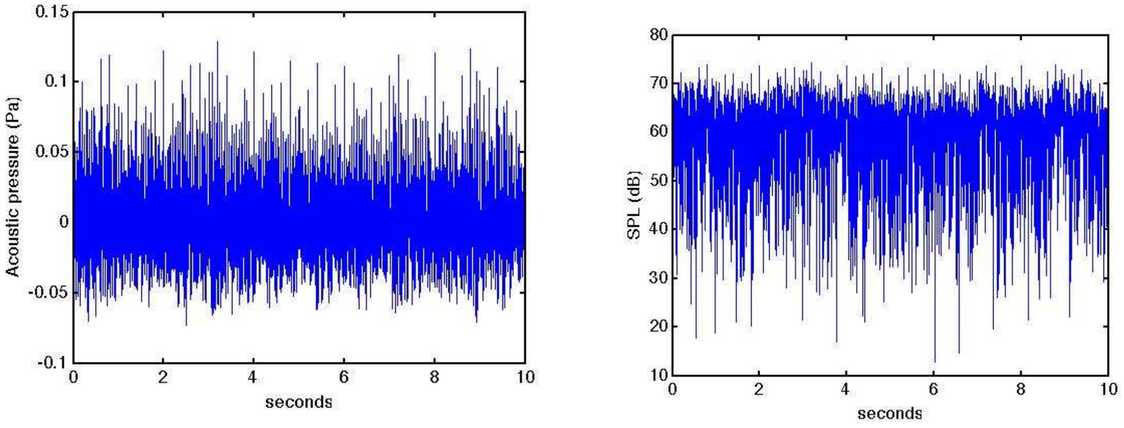
AD.4 Sound Power

Sound intensity and sound power are also often reported. Sound intensity is a measure of the energy transported per unit area and time in a certain direction. It can be shown that the intensity (I) perpendicular to the direction of sound propagation is related to the amplitude of the pressure wave squared, the density of the air (ρ), and the speed of sound (c), $I \sim p^2/\rho c$. The sound power, P, is the total intensity passing through a surface around a sound source. Intensity has units of Watts per square meter (W/m^2) and Power is measured in Watts (W). Both of these quantities are normally reported in dB where the intensity level is calculated as $L_I = 10 \log_{10} (|I|/I_{ref})$ and the power level is calculated as $L_W = 10 \log_{10}(P/P_{ref})$. The reference intensity level is related to the threshold of hearing at 1000 Hz such that $I_{ref} = 10^{-12}$ W/m^2. The reference power value is $P_{ref} = 10^{-12}$ W (1 picowatt). Here a doubling of the power leads to a 3 dB increase in the sound power level (PWL).

AD.5 Example Data Analysis

This is an example of the type of analysis done on sound measurements from a wind turbine. First, the actual signal might look something like what is shown in Figure AD.2.

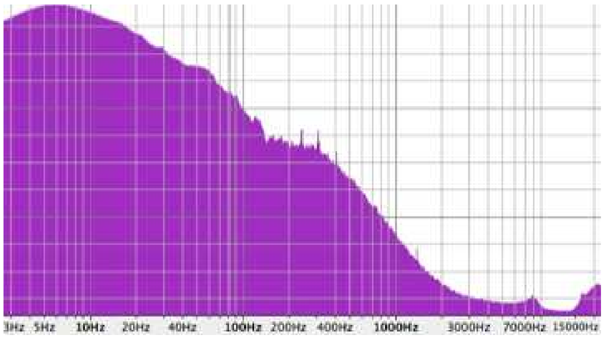
Figure AD.2: Pressure signal from a wind turbine



. *(From(van den Berg, 2011), related to Rheine wind turbine farm). Left in Pascals, right as SPL in dB.*

In Figure AD.2, just the acoustic pressure is shown, which means that atmospheric pressure, which is about 103,000 Pa, has been subtracted and the fluctuations then appear around 0 Pa. These data can easily be presented as SPL by transforming the pressure from Pa to dB. In order to analyze the pressure signal for low frequency content, a much longer time signal must be obtained. The frequency content of a long time signal is analyzed by performing a Fourier Transform. A typical transform of data from a wind turbine is shown in Figure AD.3.

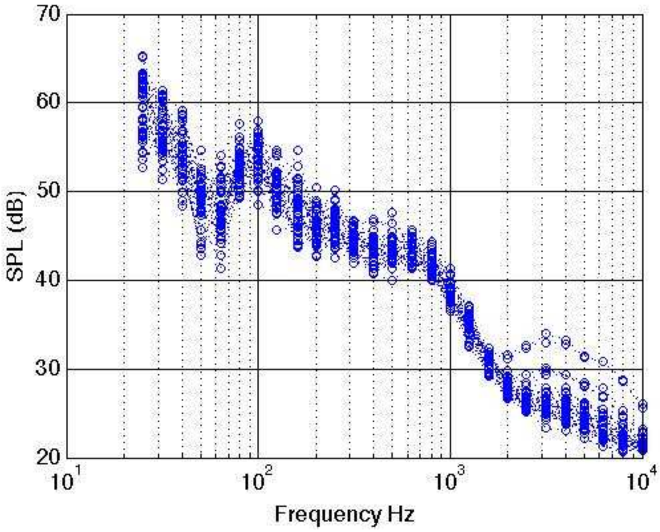
Figure AD.3: Frequency content of typical wind turbine measurement. (from Palmer ASA paper.)



(This figure does not correspond to the Rheine data for which the writer is not able to produce the full frequency domain plot.)

In order to better assess the broadband nature of wind turbine sound, the results are presented in 1/3-octave band form. The averages that are taken in each 1/3-octave band can be done on fast or slow time intervals. For instance, the data in Figure 3 could be averaged on 1/3-octave bands to come up with the overall SPL in the bands. Or, as a measurement is being taken, the instrumentation can provide 1/3-octave band averages on short time scales. For the Rheine data a fast average on 0.05 seconds was recorded. A few of the 1/3-octave band results are shown in Figure AD.4.

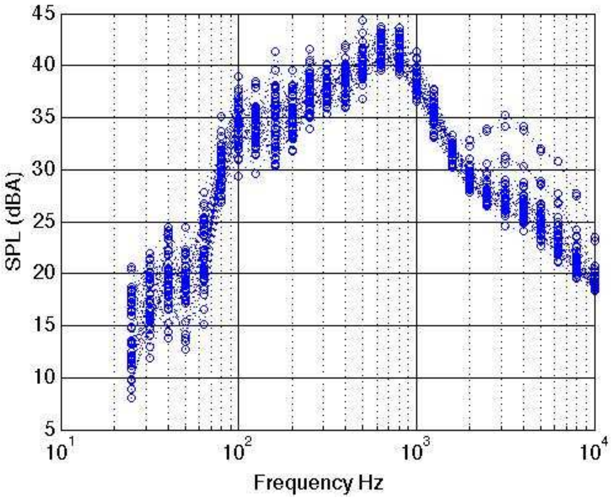
Figure AD.4: Fast averages for 1/3-octave band analysis.



Shown results for 0–0.05, 5–0.05, 10–10.05, …, 200–200.05 seconds.

From these a final overall spectrum emerges. If these were presented as A-weighted spectrum, then Figure AD.5 is what is presented.

Figure AD.5: Fast averages for 1/3-octave band A-weighted analysis.



Shown results for 0–0.05, 5–0.05, 10–10.05, …, 200–200.05 seconds.

AD.6 Wind Turbine Noise from Some Turbines

What is known about aerodynamically generated noise from wind turbines is that it nominally increases with increasing wind speed until the max power is obtained, and it increases with increasing rotor tip speed. A report out of the Netherlands by (van den Berg et al., 2008) reports a vast amount of noise data related to wind turbines. The tables in Appendices B and C from the report clearly show these trends. Some of the data are reproduced here. Only measurements that were made by third parties (not specified by the wind turbine company) are reproduced here.

Table AD.3:

Sound power level in dB(A) from various wind turbines. (van den Berg et al., 2008).

Manufacturer **Make and model**	**Power** **kW**	**Hub Height** **m**	**Diameter** **m**	**rpm**	**4 m/s**	**5m/s**	**7m/s**	**8m/s**	**10m/s**
Enron TW1.5s	1500	80	70	11	100	100	100	100	
Enron TW1.5s	1500	81	70	22		102	102	103	104
NegMicon NM52	900	70	52	15	93	93			
NegMicon NM52	900	70	52	22		98	100	101	103
NegMicon NM54	950	46	54	15		95.6			
NegMicon NM54	950	46	54	22		101.6			
Vesta V66	1650	70	66	15	97	97	98	98	
Vesta V66	1650	70	66	19		101	101	102	102

It must be noted here that what has been reported are the sound power levels, which represents the total sound energy that propagates away from the wind turbine (i.e., the sound energy at the center of the blades, which propagates outward at the height of the hub). The sound level measured at a single position at the base of the turbine can easily be 50 dB lower (Lawrence rep.).

AD.7 Definition of Infrasound

Discussion of the aerodynamic source of sound known as thickness noise or self-noise requires one to define low frequency sound and infrasound. By definition, infrasound is a pressure wave that is not audible. Nominally this means waves with frequency less than 20 Hz. It is noted though that waves with high enough amplitude below 20 Hz may still be audible. Low frequency sound is characterized as having a frequency between 20 and 200 Hz. As mentioned earlier, some mechanical noise sources contribute to the low frequency range, and clearly some of the aerodynamic sources of broadband sound will contribute to noise in the low frequency range. Thickness noise, if present, would have an associated frequency equal to the blade passing frequency. Hence, a turbine with 3-bladed rotor turning at 20 rpm might generate thickness noise at a frequency of 1 Hz, which is clearly in the infrasonic range. Downwind rotors produce slightly stronger infrasound at the blade passing frequency because the blades interact directly with the wake behind the tower. The levels of the thickness noise generated by modern upwind turbines are not perceptible by the human auditory system. Any impulsive noise that is audible, which seems to have a frequency equivalent to the blade passing frequency, is actually the broadband noise generated by the other mechanisms being modified by differences in the flow that occur on a once-per-rev basis as discussed above. The frequencies of this pulsating sound are all in the audible range, and thus this sound is not infrasound.

Appendix E

Wind Turbine – Sound Power Level Estimates and Noise Propagation

AE.1 Approximate Wind Turbine Sound Power Level Prediction Models

The following are some approximate equations that are sometimes used to estimate the A-weighted sound power level, L_{WA}, from a typical wind turbine. The first equation gives the estimate in terms of the rated power of the turbine, P_{WT} (W). The second gives the estimate in terms of the diameter, D (m). The third gives it in terms of both the tip speed, V_{Tip} (m/s), and diameter. These equations should only be used when test data is not available.

$$L_{WA} = 10(\log_{10} P_{WT}) + 50 \tag{38}$$

$$L_{WA} = 22(\log_{10} D) + 72 \tag{39}$$

$$L_{WA} = 50(\log_{10} V_{Tip}) + 10(\log_{10} D) - 4 \tag{40}$$

AE.2 Sound Power Levels due to Multiple Wind Turbines

When multiple wind turbines are located close to each other, the total sound power can be estimated by applying logarithmic relations. For example, for two turbines with sound power levels L_{W1} and L_{W2}, the total sound power is:

$$L_{total} = 10 \log_{10} (10^{L_1/10} + 10^{L_2/10}) \tag{41}$$

For N turbines, the corresponding relation is:

$$L_{total} = 10 \log_{10} \sum_{i=1}^{N} 10^{L_i/10} \tag{42}$$

where L_{wi} is the sound power level of the i^{th} turbine. For turbines that are some distance away from each other the mathematics is more complicated, and the relations of interest (actually the sound pressure level) take into account the relative position of the turbines and the location of the observer as described below.

AE.3 Noise Propagation from Wind Turbines

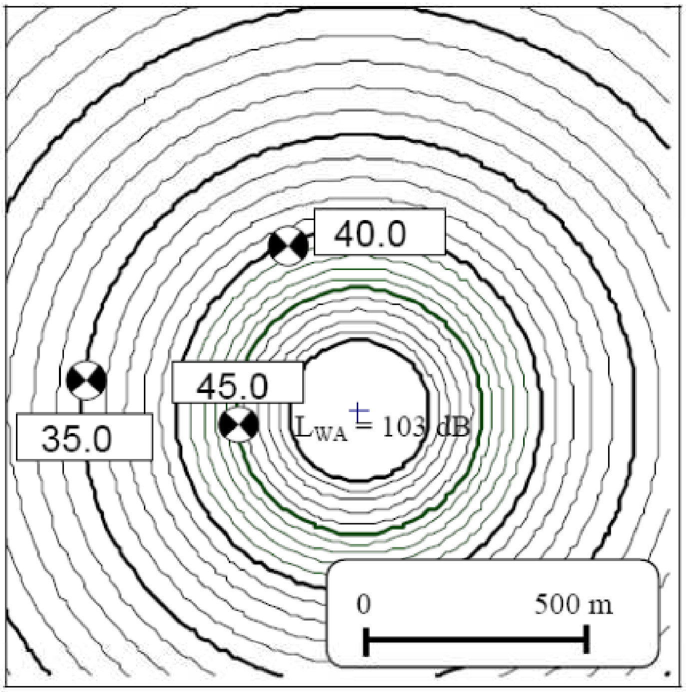
The sound pressure level will decrease with distance from a turbine. For estimation purposes, a simple model based on hemispherical noise propagation over a reflective surface, including air absorption, is given as:

$$L_p = L_W - 10\log_{10}(2\pi R^2) - \alpha R \qquad (43)$$

where L_p is the sound pressure level (dB) a distance R from a noise source radiating at a power level L_W (dB) and α is the frequency-dependent sound absorption coefficient. For broadband estimates the absorption coefficient is often approximated by a constant value of 0.005 dB(A)/m.

Figure AE.1 (from Materialien 63) indicates the sound pressure level as a function of distance from a single wind turbine with a sound power level of 103 dB(A).

Figure AE.1: Typical sound pressure level vs. distance from a single wind turbine (From Materialien 63)



The results are summarized in Table AE-1.

Table AE-1

Sound pressure level vs. distance

Sound Pressure, dB(A)	**Distance, m**
45	280
40	410
35	620

It may be seen that Equation 43, using the broadband absorption coefficient, predicts results close to those in the table (270 m, 435 m, and 675 m respectively).

AE.4 Noise Propagation from Multiple Wind Turbines

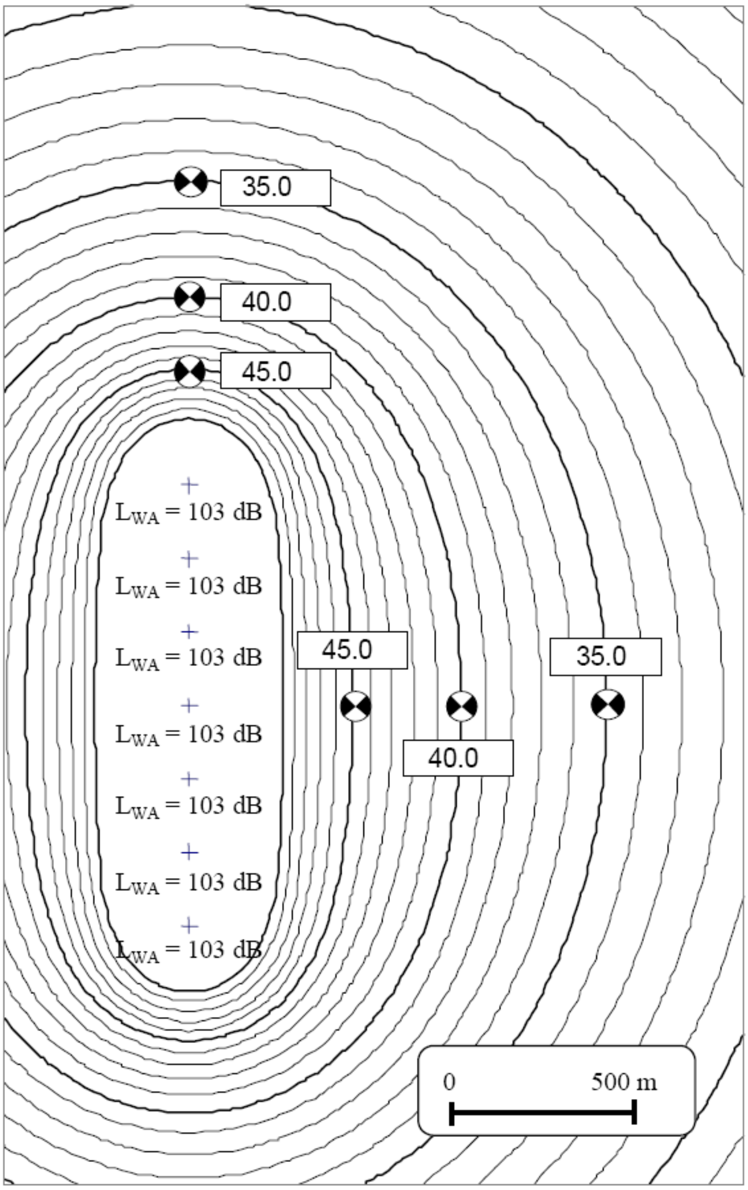
The sound perceived at a distance from multiple wind turbines is a function of the sound power level from each wind turbine and the distance to that turbine. The perceived value can be approximated by the following equation:

$$L_p = 10 \log_{10} \left[\sum_{i=1}^{N} \frac{10^{\left(L_{W,i}/10 - \alpha R_i/10\right)}}{2\pi R_i^2} \right] \qquad (44)$$

Where R_i is the distance to the ith turbine.

Figure AE-2 illustrates the sound pressure level at various distances and directions from a line of seven wind turbines, each of which is operating at a sound power level of 103 dB(A).

Figure AE.2: Sound pressure level due to a line of seven wind turbines, each operating at a sound power level of 103 dB(A) (from Materialien 63



The results are summarized in the Table AE-2.

Table AE 2:

The distances shown are in the direction perpendicular to the line of the turbines

Sound Pressure, dB(A)	**Distance**
45	440
40	740
35	1100

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Appendix F

Wind Turbine – Stall vs. Pitch Control Noise Issues

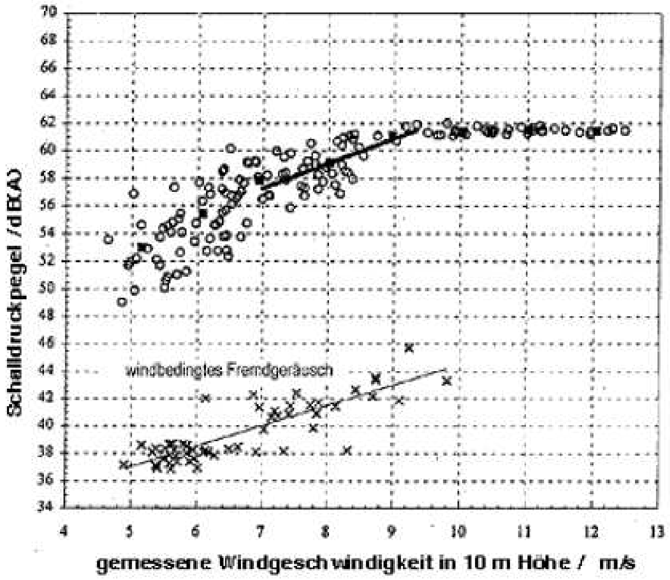
As noted in Appendix A, pitch regulated turbines are quieter than those with stall control. This is particularly the case at higher wind speeds. This appendix illustrates the difference, based on one source.

AF.1 Typical Noise from Pitch Regulated Wind Turbine

The figure below illustrates sound pressure level as a function of wind speed from a pitch regulated wind turbine (The data was taken at an unspecified distance from the turbine).

As can be seen, the noise level increases with wind speed up to a certain wind speed, here 9 m/s. After that wind speed is reached the blade pitch regulates the power and the noise level remains constant.

Figure AF.1: Sound pressure vs. wind speed from a pitch regulated wind turbine (from Materialien 63)



y-axis: sound pressure level, dB(A)

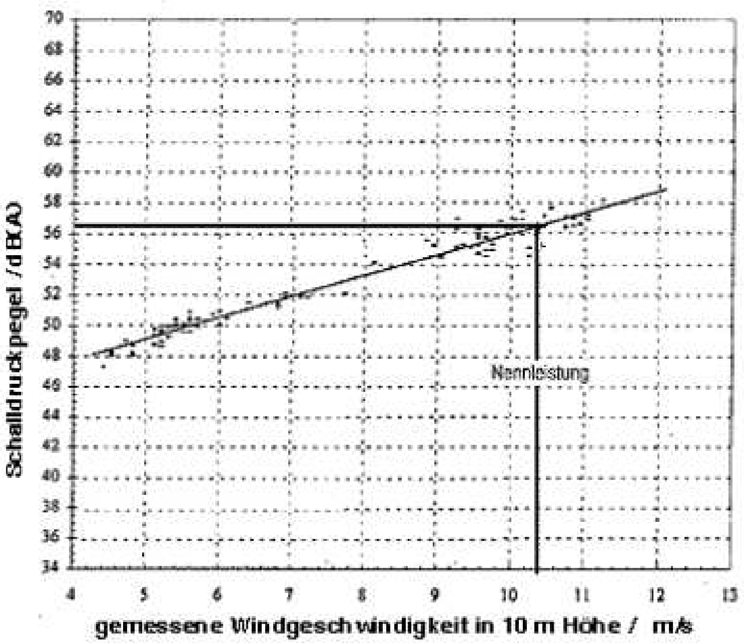
x- axis measured wind speed at 10 m height, m/s

lower line: wind-induced background noise

AF.2 Noise from a Stall Regulated Wind Turbine

The figure below illustrates sound pressure level as a function of wind speed from a stall controlled wind turbine (The data was taken at an unspecified distance from the turbine).

Figure AF.2: from Materialien 63



y-axis: sound pressure level, dB(A)

x- axis measured wind speed at 10 m height, m/s

The rated wind speed of this turbine is 10.4 m/s

As can be seen, the noise level increases approximately linearly with wind speed and does not level off.

Appendix G

Summary of Lab Animal Infrasound and Low Frequency Noise (IFLN) Studies

Table AG.1

Summary of Lab Animal Infrasound and Low Frequency Noise (IFLN) Studies

Study #	Animal Model	Endpoint	"Dose"	Timing	Measured Effects	Notes	Citation
1	Male Sprague-Dawley rats; 32 rat, 10 wks	Cardiac: ultrastructure observations, Ca2+, SERCA2 expression	5 Hz at 130 dB	2 hrs - 1 day	inc in [Ca2+]*I*; sig inc. SERCA2	No noted observation of frank toxicity. Responses increased across groups; heart rates increased in 1 day group, not in others; left ventricular pressures increased with dose chamber; Animal dose is at or slightly below 5 Hz/130 dB; Pentobarb anesthesia	Pei et al., 2007
			5 Hz at 130 dB	2 hrs - 7 days	inc in [Ca2+]*I*; Sig decr. In SERCA2 compared with control & 1 day		
			5 Hz at 130 dB	2 hrs - 14 days	inc in [Ca2+]*I*; Sig decin SERCA2 compared with control and 7 day group		
2	Male Adult Sprague-Dawley rats	Cardiac: whole-cell L-type Ca2+ currents (WLCC) in rat ventricular myocytes	5 Hz at 130 dB	2 hrs - 1 day; examined 1, 7 or 14 days post-exposure	Inc in [Ca2+](I) levels, LCC & SERCA2	No noted observation of frank toxicity. [Ca2+](I) levels as well as expression of LCC and SERCA2 may contribute to the infrasound exposure-elicited cardiac response; cannot concur with micrograph data	Pei et al., 2009
3	Male Sprague-Dawley rats	Neuronal release of stress-induced hormones	16 Hz at 130 dB	2 hrs - single exposure	activation of microglial cells and upregulation of Corticotrophin releasing hormone receptor (CRH R1); also upregulation expression is blocked by antalarmin	No noted observation of frank toxicity. .Measured in the hypothalamic paraventricular neurons. Antalarmin is a non-peptide drug that blocks the CRF-1 receptor, and, as a consequence, reduces the release of ACTH in response to chronic stress	Du et al., 2010
4	Male Sprague-Dawley rats	Neurogenesis	16 Hz at 130 dB	2 hrs/day - 7 days (sacrificed at 3, 6, 10, 14 & 18 days post-exposure)	Measured early migration and differentiation in newly generated progenitor cells by examining BUdR uptake in cells in the hippocampus (dentate gyrus)	No noted observation of frank toxicity. Authors conclude infrasound inhibits cell proliferation and that effects on proliferation appear to be reversible in the 18 days post exposure groupbackground - 40 dB; authors report reversibility, but the data don't support this - also, comparisons are with the "normal" group (in chamber, but no infrasound) but no comparison with control.	Liu et al., 2010
5	Male Albino Wistar Rats	Neural: Behavioral Performance - vestibular function	16 Hz at 72-105 dB		Rota-rod Treadmill evaluation	No noted observation of frank toxicity. Rats selected for superior performance were unaffected, but inferior rats were less able to perform for as long at same exposures.	Yamamura & Kishi, 1980
6	Male Wistar rats	Neurological - biochemical	2 Hz at 105 dB	1 hr & then sac'd	Measured brain neurepinephrine levels	No noted observation of frank toxicity. No control to determine whether Norepi levels were due to experimental design - not well controlled.	Spyraki et al., 1978
			7 Hz at 122 dB	1 hr & then sac'd	Measured brain neurepinephrine levels		
			26 Hz at 124 dB	1 hr & then sac'd	Measured brain neurepinephrine levels		
7	Female rats - no strain given	Neural	2 Hz at 105 dB 7 Hz at 122 dB 16 Hz at 124 dB		Observations made about rats' activity	Decreased time to sleep and decreased activity. Chamber and set-up is somewhat archaic and confirmatory measures are not made.	Spyraki et al., 1978
8	adult male Sprague-Dawley rats	Neural: hippocampus - dependent spatial learning and memory	16 Hz at 130 dB	14 days	Observations made using Morris water maze, measured expression and protein levels of brain-derived neurotrophic factor-tyrosine kinase receptor B.	No noted observation of frank toxicity. Calibration of sound chamber not discussed.	Yuan et al., 2009

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The views and opinions expressed in this report are solely those of the original authors, the expert panelists whose research focused on the topic of the potential health impacts associated with wind turbines. These views and opinions do not necessarily represent the views and opinions of the University of Massachusetts or the UMass Donahue Institute.

SOUTH DAKOTA DEPARTMENT OF HEALTH

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Office of the Secretary

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SOUTH DAKOTA PUBLIC
UTILITIES COMMISSION

October 13, 2017

Public Utilities Commission Staff
SD Public Utilities Commission
Capitol Building, 1st floor
500 East Capitol Avenue
Pierre, SD 57501-5070

Re: PUC Docket EL17-028 - In the Matter of the Application by **Crocker Wind Farm, LLC** for a Permit of a Wind Energy Facility and a 345 kV Transmission Line in Clark County, South Dakota, for Crocker Wind Farm

Dear PUC Staff:

The South Dakota Department of Health has been requested to comment on the potential health impacts associated with wind facilities. Based on the studies we have reviewed to date, the South Dakota Department of Health has not taken a formal position on the issue of wind turbines and human health. A number of state public health agencies have studied the issue, including the Massachusetts Department of Public Health[1] and the Minnesota Department of Health[2]. These studies generally conclude that there is insufficient evidence to establish a significant risk to human health. Annoyance and quality of life are the most common complaints associated with wind turbines, and the studies indicate that those issues may be minimized by incorporating best practices into the planning guidelines.

Sincerely,

Kim Malsam-Rysdon

Kim Malsam-Rysdon
Secretary of Health

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[1] http://www.mass.gov/eea/docs/dep/energy/wind/turbine-impact-study.pdf

[2] www.health.state.mn.us/divs/eh/hazardous/topics/windturbines.pdf