



County of San Diego

NICK MACCHIONE, FACHE
AGENCY DIRECTOR

HEALTH AND HUMAN SERVICES AGENCY
PUBLIC HEALTH SERVICES
3851 ROSECRANS STREET, MAIL STOP P-578
SAN DIEGO, CA 92110-3134
(619) 531-5800 • FAX (619) 542-4186

WILMA J. WOOTEN, M.D., M.P.H.
PUBLIC HEALTH OFFICER

February 25, 2019

PUBLIC HEALTH POSITION STATEMENT

Human Health Effects of Wind Turbines

INTRODUCTION AND PURPOSE

Introduction

The County of San Diego Planning Commission held a series of meetings on the Wind Energy Ordinance, and at their May 11, 2012 meeting, requested a report on the potential health effects of wind turbines, which was issued by Public Health Services on July 10, 2012 (1). On July 20, 2012, the Planning Commission recommended approval of the Wind Energy Ordinance and requested staff to report back with an update to this report on potential health effects of wind turbines within three years.

The Board of Supervisors (Board) considered and approved the Wind Energy Ordinance on May 15, 2013. The 2012 Position Statement was included in the Board report, and in their decision, the Board determined that public health issues were adequately addressed.

Purpose

There is ongoing debate with respect to the relationship between audible and inaudible features of wind turbines and reported health concerns. To make informed decisions, those interested in this debate rely on two key sources: scientific peer-reviewed studies published in scientific journals and the popular literature and internet. The purpose of this position statement is to provide an update to the public health position statement, dated July 10, 2012. This updated position statement will summarize conclusions from the most recent literature, with respect to any causal link or other associations between wind turbines and individual health or public health concerns.

METHODOLOGY

There are four sources of information that inform the debate of adverse health effect of wind turbines. These include peer-reviewed studies research studies published in scientific journals, government agency reports, legal proceedings, and popular literature and internet. This position statement will rely on peer-reviewed original research and review articles published in scientific journals and government agency reports to identify the latest evidence related to the potential adverse health effects of wind turbines.

Review of the science related to overall noise, low-frequency noise and infrasound, electromagnetic fields (EMFs) interference, and shadow flicker – factors potentially associated with the health impact of wind turbines – will be presented. Some of these articles examine noise and symptoms, based on the distance from the wind turbines. Additionally, articles discussing annoyance and the psychological aspect of perceiving symptoms were also reviewed. Approximately 80 recent papers and studies, published in credible, peer-reviewed journals, as well as government reports, were reviewed focusing on those published since 2012.

WIND TURBINE FEATURES ASSOCIATED WITH HEALTH CONCERNS

Background

The prevailing research on concerns regarding the adverse health effects of wind turbines focus on the impact of overall noise, low-frequency noise and infrasound, electromagnetic fields (EMFs) interference, and shadow flicker associated with wind turbines. A review of the literature has been conducted to identify the evidence for adverse side effects related to each of these wind turbine features. A number of studies also have been published examining “annoyance” and the “psychological” aspect of perceiving and/or reporting of symptoms from “Wind Turbine Syndrome” or WTS (2). This syndrome is defined as sleep disturbance, headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory, and panic episodes associated with sensations of internal pulsation or quivering when awake or asleep. This research has *been consistently rejected as biased and not based on facts or science*. Several physicians associated with anti-wind groups have recorded these symptoms from community members living near wind turbines. Instead, fear, annoyance, rumors, and the spread of unscientific, poorly documented “studies” can be responsible for the symptoms reported by some individuals.

Review Articles and Studies

Overall Noise

Noise is defined by the World Health Organization (WHO) as “unwanted sound” (3). The vast majority of research indicates no direct human health impact from industrial wind turbines (IWTs) (4, 5, 6). There is limited evidence that indicates otherwise, as seen in the *Canadian Journal of Rural Medicine* (7), where Jeffrey and colleagues review article found that industrial wind turbines produce sound that is perceived to be more of a nuisance than other sources of sound (8,9). Reported adverse health effects include annoyance, sleep disturbance, stress-related health impacts, and reduced quality of life (8, 10-15), and reported by those individuals exposed to IWT. Conversely, Bakker et al. found that “people, animals, traffic, and mechanical sounds were more often identified as a source of sleep disturbance than wind turbines (4).”

The Canadian article (7) concluded that “if placed too close to residents, IWTs can negatively affect the physical, mental and social well-being of people.” The article goes on to conclude that “...there is sufficient evidence to support the conclusion that noise from audible IWTs is a potential cause of health effects. Conversely, Knopper and colleagues (6) reviewed over 60 scientific, peer-reviewed articles and government reports that examined the noise levels produced by wind turbines, perception of wind turbine

noise, and/or responses to wind turbine noise. While many reports have found no direct causal evidence linking wind turbines to adverse health effects, the majority of the research is associated with annoyance caused by sound and visual cues, or indirect health impacts may be caused by annoyance factors (4, 9, 16-19). The Massachusetts Wind Turbine Health Impact Study found 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 (20). While no *direct* effects of wind turbine noise on sleep disturbance or psychological stress has been demonstrated, a dose–response relationship was found between emission levels of wind turbine sound and self-reported noise annoyance (4). A growing body of research supports annoyance due to perceived wind turbine noise, visualization of structures, or knowledge of the presence of the structures (4, 7, 8, 10).

Low-Frequency Noise and Infrasound

Low-frequency noise and infrasound are airborne pressure waves that occur at frequencies ≤ 200 Hz. There is much debate as to whether these sounds are audible to the human ear. Claims that infrasound from wind turbines directly impacts the vestibular system leading to direct health impacts have not been sufficiently demonstrated scientifically. Several studies (21-25) have addressed the concern of low-frequency noise (LFN) and infrasound from wind turbines as a causative agent in health effects of those living near these structures. However, while inaudible, low-frequency noise and infrasound from IWTs cannot be ruled out as plausible causes of *indirect* health effects (4, 5, 21, 26-27), available evidence shows that the infrasound levels near wind turbines cannot impact the vestibular system (20). Additionally, infrasound and LFN are not unique to wind turbines, as natural sources exist related to ocean waves, wind, and any effect that leads to slow oscillations of the air (22). At distances as close as 68 meters (223 feet), the measured levels of infrasound produced by modern upwind wind turbines are well below that required for non-auditory perception. This would include perceptions of vibration in the body or pressure in the chest. (20).

In an Australian report (28), people living near wind turbines with serious health complaints was estimated to be 10–15%. However, according to literature reviews on the health effects of wind turbines (20, 29-34), there is no evidence that wind turbines caused adverse health effects in people living in the vicinity of wind turbines, other than annoyance and self-reported sleep disturbance, the latter of which is inconclusive. In a study by Bakker and colleagues, a clear correlation between annoyance and self-reported sleep disturbance (4) was determined.

In a review of the literature by McCunney et al. (33), studies included results from field measurements of wind turbine-related sound and experimental studies in which people were purposely exposed to infrasound. It was concluded that there is no scientific evidence to support the hypothesis that wind turbine infrasound and low-frequency sound caused adverse health effects. Furthermore, reviews by McCunney et al. (33) and Harrison (35) concluded that there is no scientific evidence to support the hypothesis that wind turbine infrasound and low-frequency sound have effects different from other sources. In addition, evidence on specific health effects of low-frequency sound is limited, with little definite evidence on specific health effects of low-frequency sound when compared to health effects from ‘normal’ sound (36). Based on existing field studies, there is insufficient evidence that living near a wind turbine is the direct cause of health effects such as mental health problems, headaches, pain, stiffness or diseases such as diabetes, cardiovascular disease, tinnitus and hearing damage.

Also, scientific reviews and panels have been conducted by several governments. In 2013, the Ontario Ministry of the Environment funded research to examine if there was a link between wind turbines and health. Findings showed a statistically significant relationship between distance people lived from wind turbines and the symptoms of disturbed sleep, vertigo and tinnitus (37).

In June 2017, French authors presented their findings of a review at the 12th IC BEN Congress on Noise as Public Health Problem (5). Examining the health effects of low frequency noise and infrasound from wind turbines, the work was the results of an independent collective review. Researchers reviewed the health concerns of people living near wind farms and stratified into two categories: 1) symptoms associated with vibroacoustic disease (VAD), and 2) symptoms constituting the wind turbine syndrome (WTS). The VAD refers to potential effects of low sound frequency. A very low level of evidence was found to support any hypothesis related to VAD and potential health risks associated with noise from wind turbines. Of the symptoms from WTS (e.g., sleep disorders, headaches, tinnitus, disturbances of balance), none were found to be associated with any specific pathology. They are notably found in syndromes of idiopathic environmental intolerance. They are, however, a set of manifestations that can be caused by stress and loss of sleep, which can become disabling. This review found that because many articles were not peer-reviewed and results were not reproducible by other researchers, a very low level of evidence was attributable to the association of VAD with wind turbines. WTS, as defined above, could also be caused by stress and sleep deprivation. Current research supports the physiology of cochleovestibular (CV) system with several mechanisms that could be activated in response to LFN and infrasound (38, 39). Data suggest that these inaudible sounds could be mediated by receptors in the CV system, but no clear evidence to support this hypothesis exists.

In November 2017, the State of California Energy Commission (CEC) issued a final project report, entitled *Public Health Research Roadmap on Emerging Electricity Systems* (40). The report sought to anticipate and prevent possible health impacts of emerging electricity systems on industry workers and surrounding communities. With respect to wind turbines, the report indicates that “further research is needed on the potential for infrasound (sound lower in frequency than 20 hertz, which is the typical limit of human hearing) from wind turbines to disrupt sleep or lead to annoyance. To date, research has not provided convincing evidence to support the relationship between turbine infrasound and other health impacts (41).” The report further identifies as a medium priority for research, to “improve infrasound exposure and impact assessment.” This would include, “exposure assessment at various turbine-receptor distances and epidemiological research on sleep disruption and annoyance from larger turbine design, controlling when possible for known confounders (42).” Many studies refer to the importance of site specific research. The CEC concluded that additional research on the health impacts of wind turbines could examine health outcomes (e.g., International Classification of Diseases (ICD)-10 codes) in areas where the majority of wind turbines are located in California (e.g., Kern County) (43).

Finally, after also concluding that there is no evidence in the literature to support the hypothesis that wind turbines are associated with adverse health effects due to infrasound and LFN, a group of Canadian and U.S. researchers (6) concluded that the weight of evidence suggests that when located and installed (sited) properly, wind turbines are not related to adverse health. The authors do refer to some ‘recommended best practices for wind turbine development in the context of human health’ and these can be examined in more detail in the *Wind Turbines and Human Health* paper (2014).

In summary, review of the available data on the health effects of infrasound reveals a strong imbalance between primary bibliographical sources (documents relating to original scientific experiments and studies) and secondary sources (scientific literature reviews or opinion articles). There are numerous literature reviews, but limited number of primary sources (i.e., research articles). This finding indicates a need for additional research. Further research would be justified, as 'none of the studies published in peer-reviewed journals so far meet the criteria for cohort or case-control studies' (44).

Electromagnetic Fields

As a field of force consisting of both electric and magnetic components, an electromagnetic field (EMF) results from the motion of an electric charge and contains a definite amount of electromagnetic energy. There has been limited research conducted on wind turbine emissions of EMF, either from the turbines themselves, or from the power lines required for distribution of the generated electricity. As such, this could be an additional area for further research.

An area of concern, cited in the 2017 CEC report, is the extraction and use of rare earth metals (i.e., neodymium and dysprosium) found in certain magnets of specific direct drive turbines. The mining process is highly energy intensive and produces a significant level of waste (45). However, given that the extraction and production are typically far from the sites of wind farms, this would not be a concern for local community health impacts.

The issue of human health impacts of the magnets and effects of electromagnetic fields (EMFs) are separate issues. There is not a great deal of literature available on the health effects related to industrial magnets, however, there is a significant body of research (6, 46-50) on the electromagnetic field impacts on public health. For this issue, research shows no direct pathological impacts on human health pertaining to the emissions from wind turbines (18, 51-52). The same review article concluded that "the weight of scientific evidence does not support a causal link between EMF and health issues at levels typically encountered by people (6)." The authors do note that there has been limited research conducted on wind turbine emissions of EMF, either from the turbines themselves, or from the power lines required for distribution of the generated electricity. However, based on the weight of evidence, it is not expected that EMF from wind turbines is likely to be a causative agent for negative health effects in the community (6).

Shadow Flicker

The U.S. Department of the Interior Office of Indian Energy and Economic Development, Tribal Energy and Environmental Information Clearinghouse defines shadow flicker as the visual, strobe-like effect that occurs when the rotating blades of wind turbines cast shadows (53). The primary health concern identified with shadow flicker is the risk of seizures in individuals with photosensitive epilepsy. A review of the literature, in 2011, by Knopper and Ollson (54), identified two seminal studies related to this concern, which was published by Harding et al. (55) and Smedley et al. (56). The relationship between photo-induced seizures (i.e., photosensitive epilepsy) and wind turbine blade flicker (known also as shadow flicker) was investigated by both authors. Both studies submitted that flicker from turbines that interrupt or reflect sunlight at frequencies greater than 3 Hz pose a potential risk of causing photosensitive seizures in 1.7 people per 100,000 of individuals who are photosensitive. For turbines with three blades, this translates to a maximum speed of rotation of 60 rpm. Current turbines commonly spin at rates well below this threshold. For four different models of wind turbines (i.e., Siemens, Repower, GE, and Vestas), as

obtained from the turbine specification sheets, the spin rates were found to be far below this threshold, ranging from 6-17.1 rpm.

The Department of Energy and Climate Change (57) released a consultant's report, entitled "Update of UK Shadow Flicker Evidence Base," in 2011. It concluded that, "*On health effects and nuisance of the shadow flicker effect, 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.*" Furthermore, the expert panel convened by MassDEP and MDPH (20) concluded that the scientific evidence suggests that shadow flicker does not pose a risk of inducing seizures in people with photosensitive epilepsy. Germany is one of the only countries to implement formal shadow flicker guidelines, which is part of the *Federal Emission Control Act* (6).

Conversely, the review article by Jeffrey and colleagues proposed that the blades of IWTs produce unavoidable shadow flicker bright enough to pass through closed eyelids, and moving shadows cast by the blades on window can affect illumination inside a building (7). The Danish Energy Agency classifies shadow flicker from IWTs experience by resident as a "nuisance" (19).

While shadow flicker from wind turbines is unlikely to lead to a risk of photo-induced epilepsy, little if any research has been conducted on how it could heighten the annoyance factor of those living in proximity to turbines. This could also be related to visual cues, as is thought to influence some people's response to wind turbines. Conversely, while some people exposed to shadow flicker from IWTs may report negative effects of health and well-being (11), most jurisdictions in Canada do not have regulations that prevent negative effects from visual impact caused by IWTs.

OTHER RESEARCH THEORIES

Annoyance

Annoyance is defined by WHO as "a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them (58). Colby and colleagues found that "'wind turbine syndrome' symptoms are not new and have been published previously in the context of 'annoyance'" and the well-known stress effects of exposure to noise...(59)" The 2014 Canadian Journal Rural Medicine article by Jeffrey and colleagues (7) reviewed the latest literature, including the Colby panel review. In the 2014 literature review by Knopper and Ollson (6), it was concluded that although there was evidence to suggest that wind turbines can be a source of annoyance to some people, there was no evidence demonstrating a direct causal link between living in proximity to wind turbines and more serious physiological health effects. Furthermore, although annoyance has been statistically significantly associated with wind turbine noise (especially at sound pressure levels >40 dB(A)), a convincing body of evidence (16, 17-19, 58,60-61) exists to show that annoyance is more strongly related to visual cues and attitude than to wind turbine noise itself. In particular, this was highlighted by the fact that people who benefit economically from wind turbines (e.g., those who have leased their property to wind farm developers) reported significantly lower levels of annoyance than those who received no economic benefit, despite increased proximity to the turbines and exposure to similar (or louder) sound levels. Finally, a 2014 critical review of the literature by McCunney and colleagues (33) found that epidemiological studies have shown associations with living near wind turbines and annoyance. They

further found that annoyance appears to be more strongly related to individual characteristics than noise from the turbines.

Nocebo Effect

A number of studies have been published examining the psychological aspect of perceiving and/or reporting of symptoms from “Wind Turbine Syndrome.” These findings would seem to indicate some form of psychological relationship to the perception of symptoms (62). Some articles indicate that those who are exposed to messages about the harmful effects of wind turbines are more likely to complain about the effects. Health complaints have primarily been located in areas that have received the most negative publicity about the harmful effects of turbines (8-10, 12, 63-64). There is also reference in the literature to the nocebo effect, similar to a placebo effect, whereby health concerns and negative expectations can trigger symptom reporting (5, 21, 26, 27, 33). In one study (22), participants were introduced to both actual infrasound and sham infrasound. Then healthy volunteers, when given information about the expected physiological effect of infrasound, reported symptoms that aligned with that information. Results suggest psychological expectations could explain the link between wind turbine exposure and health complaints.

On a similar note, another study (4) found that those who do not hear the noise or report disturbance are not seen to be impacted. This would imply that the effects, if any, are not uniformly impacting proximal communities. This study reported that, “No direct effects of wind turbine noise on sleep disturbance or psychological stress has been demonstrated, which means that residents, who do not hear the sound, or do not feel disturbed, are not adversely affected.”

Other Review Articles

Since 2012, a number of papers and journal articles have examined the latest published research regarding potential health effects associated with wind turbines. One such article, published in 2013, concluded that there could be some evidence that infrasound (sound of too low a frequency to hear) could affect the vestibular system, making ‘Wind Turbine Syndrome’ a potentially plausible condition. The article also indicates that many believe, however, that these symptoms are related largely to stress and any potential effects require further investigation (65). Schmidt and colleagues (66), summarizing a comprehensive literature review, concluded that exposure to wind turbines seems to increase the risk of ‘annoyance’ and self-reported sleep disturbance in a dose-response relationship. This paper identifies LAeq of 35 dB as a tolerable level of sound. It further determined that no conclusive evidence could be found demonstrating that exposure to wind turbines is responsible for the many other health effects alleged to be associated with exposure to wind turbines. The paper concludes that additional research should focus on objectively demonstrating whether or not measurable health-related outcomes can be proven to fluctuate depending on exposure to wind turbines.

One recent 2014 study (67), by the Government of Canada, sought to do that. They investigated the prevalence of health effects or health indicators among a sample of Canadians in two provinces exposed to Wind Turbine Noise (WTN) using both self-reported and *objectively measured* health outcomes. They also applied statistical modeling in order to derive exposure response relationships between WTN levels and self-reported and objectively measured health outcomes. The study methodology was put through a 60-day public consultation and peer review process. The following were *not* found to be associated with

WTN exposure: self-reported illnesses including dizziness, tinnitus, prevalence of frequent migraines and headaches, chronic health conditions including heart disease, high blood pressure and diabetes, self-reported sleep disturbances, use of sleep medication or diagnosed sleep disorders, and self-reported perceived stress and quality of life. While some people did report some of these health conditions, the prevalence was not found to change in relation to exposure to WTN. This study by the federal government of Canada found that the evidence did not support an association between wind turbine noise levels and sleep quality. Objectively measured health outcomes were consistent and statistically related to corresponding self-reported results. WTN was not related to hair cortisol concentrations (cortisol is a well-established biomarker of stress and measurement of hair cortisol levels make it possible to retrospectively examine months of stressor exposure), blood pressure, resting heart rate or measured sleep (e.g., sleep latency, awakenings, sleep efficiency) following the application of multiple regression models. Sleep was measured using a compact wrist-worn monitor over several days. WTN was not associated with sleep disturbance of any kind.

The only element that was found to be statistically associated with increasing levels of WTN was 'annoyance' towards several wind turbine features such as those previously mentioned in the paper, namely noise, shadow flicker, blinking lights, vibrations, and visual impacts. At the highest WTN levels (greater than or equal to 40 dBA) the percentage of residents who responded as being highly annoyed at the two test sites were only 16.5% and 6.3%. A statistically significant increase in annoyance was found when WTN levels were over 35 dBA (A-weighted decibel, a unit of sound). For even the most vulnerable people, the World Health Organization determined, in *Night Noise Guidelines for Europe* (68), that 40 dBA is the level below which no health effects are associated with sleep disturbance. As for infrasound, the levels sampled close to the base of the turbine were approximately the threshold of audibility reported by the 1% of people with the most sensitive hearing. So the infrasound should not be detectable by the vast majority of people. Distance from the wind turbines was correlated with community annoyance, so proper siting distance is important to reduce community reported annoyance (67).

DISCUSSION

Adverse Health Impact or Annoyance?

To anticipate and prevent harmful effects, and instead maximize potential health benefits, of emerging energy systems, such as wind turbines, a review of the literature to examine the latest research is necessary. The reviewers concluded that the available scientific evidence suggests that low-frequency noise and infrasound, EMF, and shadow flicker from wind turbines are *not* likely to affect human health (67). Based on the available research, it is reaffirmed that the current state of research indicates no conclusive, direct, causal link between wind turbines and adverse health outcomes or impacts. There are, however, well documented reported cases (4-10, 16-20, 38, 59, 66, 67), in varying degrees, of what is formally referred to, in academic journals, as 'annoyance' by a minority of community members. Annoyance, while not a *direct*, negative health impact, can be understood to result in *indirect* health impacts, such as irritability and sleep disturbance, which may, in turn, produce its own impacts on individual health (i.e., headaches, difficulties with concentration, dizziness, and changes in metabolism).

Benefit to Individual Health, Health Care Systems, and Public Health

Given wind turbines may be the healthier choice, when compared to traditional fossil fuels, advantages compared to challenges must also be considered. Alternative sources of energy, such as wind energy, can have significant *benefit* to individual health (e.g., lung health), health care systems (e.g., cost savings), and public health (e.g., air quality). Benefits to the individual, public health, and health care systems are discussed in this section.

Benefit to Individual Health

The WHO Ambient Air Pollution database, derived from measurements taken in 1,600 cities in 91 countries, reveals that almost nine out of 10 individuals, living in urban areas, are affected by air pollution (69). For 2010, exposure to outdoor air pollution is cited as the ninth leading risk factor for mortality, and responsible for 3.2 million deaths each year (70). A comprehensive review of the literature (71), published in the *Current Opinion in Pulmonary Medicine* (2016), reaffirmed that air pollution enhances pulmonary disease and causes greater harm in susceptible populations, such as children, the elderly, and those of low socio-economic status. Conditions such as asthma, chronic obstructive pulmonary disease, lung cancer, and respiratory infections may all be exacerbated because of exposure to environmental air pollutants, such as particulate matter, ozone, and nitrogen oxides. New publications appraised in the review article reaffirm these findings. Hence, solutions to improve air pollution translate into a positive impact on lung health.

Benefit to Healthcare System

A recent publication, in the *British Medical Journal*, cited that “reducing air pollution can provide significant health benefits, including reducing asthma, chronic obstructive pulmonary disease, cancer, and heart disease, which in turn could provide significant savings for the healthcare system (72). Further research is needed to identify if there is a disproportionate number of medical codes (also known as International Classification of Diseases (ICD) -10 codes) reported in areas near windfarms that may be associated with a cluster of symptoms (e.g., headaches, vertigo, dizziness). The 2012 *Rural Health Status Report* (73), produced by the County of San Diego, provides a means of sharing information about the health of rural residents in San Diego County. The *Report* does not demonstrate a disproportionate number of these issues regionally. However, there are certain trends in local, rural health that may have a bearing on the incidence of these related symptoms, such as a higher proportion of chronic disease of older residents, who would be more inclined to report similar symptoms as a factor of aging. More cohort or case-control studies are needed to establish any significant association or causation.

Benefit to Public Health

For decades, globally, wind power has been harnessed as a source of energy, and could be considered a mitigating measure to promote public health, and decrease the greenhouse gas footprint to support climate change efforts. According to the 2017 CEC report (74), emerging energy systems, such as wind turbines, have been found to have life-cycle carbon dioxide emissions of fewer than 50 grams of carbon dioxide equivalent (CO₂e) per kilowatt hour (gCO₂e/kWh). In comparison, coal power plants generate 800-1000 gCO₂e/kWh (75). Natural gas plants, more prevalent than coal use in California, produce an

estimated 600 gCO₂e/kWh over the life cycle. Based on this information, the potential health impacts across the life cycle, of renewable energy systems from wind farms, appear to be significantly smaller than those attributed to fossil fuel electricity production.

Data Limitations

The major limitation of most of the studies referred to in this literature review is that they are literature reviews, mainly observational in nature, or rely on self-reporting as opposed to original scientific research. It can be difficult to undertake the kind of scientific research required to extract and measure any direct effects (e.g., randomly assigning various groups of people to live in proximity to wind turbines while controlling for various factors such as preexisting health conditions). There is also no way to blind subjects to their proximity. Additionally, some of the data is based on surveys, which introduces an element of selection bias and other issues (e.g., self-reporting).

But even the more rigorous studies are largely subjective. There is good reason to suspect that confounding variables may be dominant in those cases. For example, a 2014 study (76) reviewed psychological factors which have been shown to influence reports of health effects from wind turbines. Subjects were more likely to report negative symptoms if they found wind turbines annoying, if they thought they were an eyesore, and if they did not gain any economic benefit from them. A 2017 Australian study (77) found that one's political view toward wind turbines largely determine how symptoms and alleged health effects are interpreted – specifically, are they caused by proximity to wind turbines.

Lastly, in addition to articles presented above for this literature review, the WHO released its guidance on environmental noises (78) with recommendations. Regarding wind turbines, for average noise exposure, a **conditional** recommendation was made to reduce noise levels produced by wind turbines below **45 dB** L_{den} .

SUMMARY

Since 2012, numerous comprehensive journal reviews and studies have been conducted around the world to examine potential adverse health effects of wind turbines. In addition to the vast majority of credible, scientific, peer-reviewed journals, evidence from numerous federal, state and local governments has been examined. Based on these findings and the scientific merit of the research conducted to date:

- An imbalance was found between the availability of primary bibliographical sources (i.e., original scientific experiments and studies) and secondary sources (i.e., scientific literature reviews). This included focus on noise, low frequency noise and infrasound, EMF, and shadow flicker.
- The majority of evidence shows that, while noise from wind turbines is not causally related to adverse health effects, wind turbines may be a source of annoyance for a small minority of community residents. That annoyance may cause stress for these individuals, and that stress may be associated with certain reported health effects.
- The weight of evidence suggests that, when sited properly, wind turbines are not related to adverse health effects.

Numerous literature reviews were found, however, limited number of primary sources (i.e., research articles) available. Additional research, such as cohort or case-controlled studies, would be needed to establish a potential causal association between wind turbines and adverse health effects.

REFERENCES

- (1) County of San Diego. Public Health Services. Position Statement on Health Effects of Wind Turbines (July 10, 2012).
- (2) Pierpont N. Wind turbine syndrome: a report on a natural experiment. Santa Fe (NM): K-Selected Books; (2009).
- (3) World Health Organization. Noise and health. Available: www.euro.who.int/en/health-topics/environment-and-health/noise (Accessed 2019 February 8).
- (4) Bakker RH, Pedersen E, van den Berg GP, Stewart RE, Lok W, Bouma J. Impact of wind turbine sound annoyance, self-reported sleep disturbance and psychological distress. *Sci Total Environ* (2012) 425:42-5110
<https://www.ncbi.nlm.nih.gov/pubmed/22481052>
<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4063257/>
- (5) Health effects of low frequency noise and infrasound from wind farms: results from an independent collective expertise in France. 12th IC BEN Congress on Noise as a Public Health problem, Jun 2017, ZURICH, Switzerland. 12th IC BEN Congress on Noise as a Public Health Problem, 9 p, 2017, p. 7.
http://www.icben.org/2017/ICBEN%202017%20Papers/SubjectArea10_Ecoti%C3%A8re_1005_2487.pdf
- (6) Knopper LD, Ollson CA, McCallum LC, Whitfield Aslund ML, Berger RG, Souweine K, and McDaniel M. Wind Turbines and Human Health. *Frontiers in Public Health*. 2014; 2: 63.
<https://www.ncbi.nlm.nih.gov/pubmed/24995266>
<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4063257/>
- (7) Jeffrey RD, Krogh CM, Horner B. Industrial wind turbines and adverse health effects. *Can J Rural Med*. 2014 Winter; 19(1);21-6.
<https://www.ncbi.nlm.nih.gov/pubmed/24398354>
<https://srpc.ca/resources/Documents/CJRM/vol19n1/pg21.pdf>
- (8) Pedersen E, Persson KW. Perception and annoyance due to wind turbine noise — a dose response relationship. *J Acoust Soc Am* 2004;116:3460-70.
- (9) Pedersen E, Bakker R, Bouma J, et al. Response to noise from modern wind farms in the Netherlands. *J Acoust Soc Am* 2009; 126: 634-43.
- (10) Pedersen E, Persson Waye K. Wind turbine noise, annoyance and self-reported health and well being in different living environments. *Occup Environ Med* 2007;64:480-6.
- (11) Krogh C, Gillis L, Kouwen N, et al. WindVOiCe, a self-reporting survey: adverse health effects, industrial wind turbines, and the need for vigilance monitoring. *Bull Sci Technol Soc* 2011;31:334-45.
- (12) Shepherd D, McBride D, Welch D, et al. Evaluating the impact of wind turbine noise on health-related quality of life. *Noise Health* 2011;13:333-9.
- (13) Thorne B. The problems with “noise numbers” for wind farm noise assessment. *Bull Sci Technol Soc* 2011;31:262-90.

- (14) Rand R, Ambrose S, Krogh C. Wind turbine acoustic investigation: infrasound and low-frequency noise — a case study. *Bull Sci Technol Soc* 2012;32:128-41.
- (15) Nissenbaum M, Aramini J, Hanning C. Effects of industrial wind turbine noise on sleep and health. *Noise Health* 2012;14:237-43.
- (16) Minnesota Department of Health. *Public health impacts of wind turbines*. St. Paul (MN): 2009. Available: www.health.state.mn.us/divs/eh/hazardous/topics/windturbines.pdf (accessed January 28, 2019).
- (17) Maschke C, Niemann A. Health effects of annoyance induced by neighbor noise. *Noise Control Eng J* 2007;55:348-56.
- (18) Havas M, Colling D. Wind turbines make waves: why some residents near wind turbines become ill. *Bull Sci Technol Soc* 2011; 31:414-26.
- (19) Danish Energy Agency. Wind turbines in Denmark. Copenhagen (Denmark); 2009. http://www.ingdemurtas.it/wp-content/uploads/2015/11/wind_turbines_in_denmark.pdf
- (20) Ellenbogen JM, Grace S, Heiger-Bernays WJ, Manwell JF, Mills DA, Sullivan KA and Weisskopf MG. Massachusetts Department of Public Health. *Wind Turbine Health Impact Study*. Report of Independent Expert Panel. P. ES-6. January 2012. [Government Report] <https://www.mass.gov/files/documents/2016/08/th/turbine-impact-study.pdf>
- (21) Crichton F, Dodd G, Schmid G, Gamble G, Cundy T, Petrie KJ. Can expectations produce symptoms from infrasound associated with wind turbines? *Health Psychol* (2014) 33:360–410.1037/a0031760 [PubMed] [CrossRef]
- (22) Leventhall G. Infrasound from wind turbines – fact, fiction or deception? *Can Acoust* (2006) 34:29–36
- (23) O'Neal RD, Hellweg RD, Jr, Lampeter RM. Low frequency noise and infrasound from wind turbines. *Noise Control Eng J* (2011) 59:135–5710.3397/1.3549200 [CrossRef]
- (24) Møller H, Pedersen CS. Low-frequency noise from large wind turbines. *J Acoust Soc Am* (2011) 129:3727–4410.1121/1.3543957 [PubMed] [CrossRef]
- (25) Bolin K, Bluhm G, Eriksson G, Nilsson ME. Infrasound and low frequency noise from wind turbines: exposure and health effects. *Environ Res Lett* (2011) 6:106.10.1088/1748-9326/6/3/035103 [CrossRef]
- (26) Crichton, Fiona, et Keith J. Petrie. 2015. "Health complaints and wind turbines: The efficacy of explaining the nocebo response to reduce symptom reporting." *Environmental Research* 140:449–455.
- (27) Tonin, Renzo, James Brett, et Ben Colagiuri. 2016. "The effect of infrasound and negative expectations to adverse pathological symptoms from wind farms." *Journal of Low Frequency Noise, Vibration and Active Control* 35 (1):77-90.
- (28) Thorne, B.: the relevance of the precautionary principle to wind farm noise planning. In: INTER-NOISE and NOISE-CON Congress and Conference Proceedings 2014 Oct 14, vol. 249, No. 3, pp. 4065–4074. Institute of Noise Control Engineering (2014).

- (29) Onakpoya, I.J., O'Sullivan, J., Thompson, M.J., Heneghan, C.J.: The effect of wind turbine noise on sleep and quality of life: a systematic review and meta-analysis of observational studies. *Environ. Int.* 30(82), 1–9 (2015).
- (30) Merlin, T., Newton, S., Ellery, B., Milverton, J., Farah, C. Systematic review of the human health effects of wind farms. National Health & Medical Research Council, Canberra (2013).
- (31) Public health effects of siting and operating onshore wind turbines. Publication of the Superior Health Council (SHC) no. 8738, Brussels. www.tinyurl.com/SHC-8738-windturbines
- (32) Schmidt, J.H., Klokke, M.: Health effects related to wind turbine noise exposure: a systematic review. *PLOS ONE* 9(12), e114183 (2014). [CrossRefGoogle Scholar](#)
- (33) McCunney, R.J., Mundt, K.A., Colby, W.D., Dobie, R., Kaliski, K., Blais, M.: Wind turbines and health: a critical review of the scientific literature. *J. Occup. Environ. Med.* 56(11), e108–30 (2014).
- (34) Council of Canadian Academies, 2015: Understanding the Evidence: Wind Turbine Noise. Ottawa (ON): The Expert Panel on Wind Turbine Noise and Human Health. Council of Canadian Academies (2015).
- (35) Harrison, R.V.: On the biological plausibility of wind turbine syndrome. *Int. J. Environ. Health Res.* 25(5), 463–8 (2015). CrossRef
- (36) Baliatsas, C., van Kamp, I., van Poll, R., Yzermans, J.: Health effects from low-frequency noise and infrasound in the general population: is it time to listen? A systematic review of observational studies. *Sci. Total Environ.* 1(557), 163–9 (2016). [CrossRefGoogle Scholar](#)
- (37) Wind turbine noise, sleep quality, and symptoms of inner ear problems. Symposia of the Ontario Research Chairs in Public Policy; 2013 Oct. 17; Toronto (ON). <https://www.wind-watch.org/documents/wind-turbine-noise-sleep-quality-and-symptoms-of-inner-ear-problems/>
- (38) Salt, Alec N. 2004. "Acute endolymphatic hydrops generated by exposure of the ear to nontraumatic low frequency tones." *Journal of the Association for Research in Otolaryngology.* 5 (2):203-214.
- (39) Salt, Alec N., et Timothy E. Hullar. (2010). Responses of the ear to low frequency sounds, infrasound and wind turbines. *Hearing Research.* 268 (1):12-21.
- (40) California Energy Commission. *Public Health Research Roadmap on Emerging Electricity Systems.* November 2017. <https://www.energy.ca.gov/2017publications/CEC-500-2017-035/CEC-500-2017-035.pdf>
- (41) California Energy Commission. *Public Health Research Roadmap on Emerging Electricity Systems.* November 2017. p. 2-3. <https://www.energy.ca.gov/2017publications/CEC-500-2017-035/CEC-500-2017-035.pdf>
- (42) California Energy Commission. *Public Health Research Roadmap on Emerging Electricity Systems.* November 2017, p. 5-6. <https://www.energy.ca.gov/2017publications/CEC-500-2017-035/CEC-500-2017-035.pdf>

- (43) California Energy Commission. Public Health Research Roadmap on Emerging Electricity Systems. November 2017, p. 55.
<https://www.energy.ca.gov/2017publications/CEC-500-2017-035/CEC-500-2017-035.pdf>
- (44) Kurpas D, Mroczek B, Karakiewicz B, Kassolik K, Andrzejewski W. Health impact of wind farms. *An Agric Environ Med*. 2013; 20(3);595-604.
<http://www.aaem.pl/Health-impact-of-wind-farms,71983,0,2.html>
- (45) California Energy Commission. Public Health Research Roadmap on Emerging Electricity Systems. November 2017, p. 50.
<https://www.energy.ca.gov/2017publications/CEC-500-2017-035/CEC-500-2017-035.pdf>
- (46) Health Canada. Electric and Magnetic Fields from Power Lines and Appliances (Catalogue # H13-7/70-2012E-PDF). Ottawa: Government of Canada; (2012).
- (47) World Health Organization (WHO). Electromagnetic Fields. (2012). <http://www.who.int/peh-emf/en/>
- (48) ICNIRP (International Commission on Non-Ionizing Radiation Protection). Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz–100 kHz). *Health Phys* (2010) 99:818–3610.1097/HP.0b013e3181f06c86. [[PubMed](#)] [[CrossRef](#)]
- (49) IARC (International Agency for Research on Cancer). Working Group on the Evaluation of Carcinogenic Risks to Humans. Nonionizing Radiation, Part 1: Static and Extremely Low-Frequency (ELF) Electric and Magnetic Fields. (Monographs on the Evaluation of Carcinogenic Risks to Humans, 80). Lyon: IARC; (2002). [[PMC free article](#)] [[PubMed](#)]
- (50) National Institute of Environmental Health Sciences. EMF-Electric and Magnetic Fields Associated with the Use of Electric Power. Questions & Answers. Research Triangle Park, NC: NIEHS/DOE EMF RAPID Program; (2002).
- (51) Israel M, Ivanova P, Ivanova M. Electromagnetic fields and other physical factors around wind power generators (pilot study). *Environmentalist* (2011) 31:161-810.1007/s10669-011-9315-z as cited in Knopper et al (2014).
- (52) 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? *Environ Health* (2014) 13:9.10.1186/1476-069X-13-9 as cited in Knopper et al (2014).
- (53) The U.S. Department of the interior Office of Indian Energy and Economic Development, Tribal Energy and Environmental Information Clearinghouse. https://definedterm.com/shadow_flicker.
- (54) Knopper LD, Ollson CA. Health effects and wind turbines: a review of the literature. *Environ Health* (2011) 10:78.10.1186/1476-069X-10-78. [[PMC free article](#)] [[PubMed](#)] [[CrossRef](#)]
- (55) Harding G, Harding P, Wilkins A. Wind turbines, flicker, and photosensitive epilepsy: Characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them. *Epilepsia*. 2008;49:1095–98. doi: 10.1111/j.1528-1167.2008.01563.x. [[PubMed](#)] [[CrossRef](#)]

- (56) Smedley ARD, Webb AR, Wilkins AJ. Potential of wind turbines to elicit seizures under various meteorological conditions. *Epilepsia*. 2010;51:1146–1151. [[PubMed](#)]
- (57) UK Department of Energy and Climate Change. Update of UK Shadow Flicker Evidence Base: Final Report. London: Department of Energy and Climate Change; (2011).
- (58) Niemann H, Maschke C. WHO LARES: final report: noise effects and morbidity. Geneva (Switzerland): World Health Organization; 2004. www.euro.who.int/_data/assets/pdf_file/0015/105144/WHO_Lares.pdf
- (59) Colby WD, Dobie R, Leventhall G, et al. Wind turbine sound and health effects: an expert panel review. Washington (DC): American Wind Energy Association and Canadian Wind Energy Association; 2009.
- (60) Berglund B, Lindvall T, Schwela DH. Guidelines for community noise. Geneva (Switzerland): World Health Organization; 1999.
- (61) Committee on Environmental Impacts of Wind Energy Projects, National Research Council. Environmental impacts of wind-energy projects. Washington (DC): National Academies Press; 2007.
- (62) Rubin, GJ, Burns M, Wessely S. Possible psychological mechanisms for "wind turbine syndrome." On the windmills of your mind. (2014) *Noise & Health*. 16:69, 116-122.
- (63) Crichton F, Chapman S, Cundy T, Petrie KJ. The Link between Health Complaints and Wind Turbines: Support for the Nocebo Expectations Hypothesis. *Front Public Health*. 2014. Nov 11;2:220. <https://www.ncbi.nlm.nih.gov/pubmed/25426482>
<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4227478/>
- (64) 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:e76584.10.1371/journal.pone.0076584. [PMC free article] [PubMed] [CrossRef]
- (65) Farboud, A. Crunkhorn, R., and Trinidad, A. Wind turbine syndrome: fact or fiction? *The Journal of Laryngology & Otology* (2013), 127, 222-226, p. 1. <https://www.ncbi.nlm.nih.gov/pubmed/23331380>
- (66) Schmidt, J.H., Klokke, M. Health Effects Related to Wind Turbine Noise Exposure: A systematic Review. *PLOS ONE*. DOI:10.1371/journal.pone.0114183. December 4, 2014. <https://www.ncbi.nlm.nih.gov/pubmed/25474326>
- (67) Government of Canada (2014). Wind Turbine Noise and Health Study: Summary of Results. <https://www.canada.ca/en/health-canada/services/environmental-workplace-health/noise/wind-turbine-noise/wind-turbine-noise-health-study-summary-results.html>
- (68) World Health Organization (2009). Night Noise Guidelines for Europe. http://www.euro.who.int/_data/assets/pdf_file/0017/43316/E92845.pdf

- (69) World Health Organization. Ambient Air Pollution Database. WHO; Geneva, Switzerland: [December 2015]. 2014.
- (70) Lim SS, Vos T, Flaxman AD, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet*. 2012;380:2224–2260. [[PMC free article](#)] [[PubMed](#)]
- (71) Kurt OK, Zhang J, and Pinkerton KE. Pulmonary Health Effects of Air Pollution. *Curr Opin Pulm Med*. 2016. Mar; 22(2): 138–143.
- (72) McCoy D, Montgomery H, Arulkumaran S, Godlee F. Climate change and human survival. *BMJ* (2014) 348:g2351.10.1136/bmj.g2351. <https://www.ncbi.nlm.nih.gov/pubmed/24671985>
- (73) County of San Diego. Health and Human Services Agency. Public Health Services. Community Health Statistics Unit. (2012). *Rural Health Status Report, San Diego County*. Retrieved 1/16/2018 from www.SDHealthStatistics.com.
- (74) California Energy Commission. Public Health Research Roadmap on Emerging Electricity Systems. November 2017, p. 11. <https://www.energy.ca.gov/2017publications/CEC-500-2017-035/CEC-500-2017-035.pdf>
- (75) Hertwich, Aloisi de Lardere, and Suh. Green Energy Choices: The Benefits, Risks, and Trade-Offs of Low-Carbon Technologies for Electricity Production. http://www.un-expo.org/wp-content/uploads/2017/06/Green_energy_choices_The_benefits_risks_and_trade-offs_of_low-carbon_technologies_for_electricity_production-2016UNEP_GEC_web.pdf.pdf
- (76) Rubin GJ, Burns M, Wessely S. Possible psychological mechanisms for "wind turbine syndrome". On the windmills of your mind. *Noise Health*. 2014 Mar-Apr;16(69):116-22. doi: 10.4103/1463-1741.132099. <https://www.ncbi.nlm.nih.gov/pubmed/24804716>
- (77) Clark S, Botterill LC. Contesting facts about wind farms in Australia and the legitimacy of adverse health effects. *Health (London)*. 2018 Jul;22(4):337-355. doi: 10.1177/1363459317693407. Epub 2017 Feb 1. <https://www.ncbi.nlm.nih.gov/pubmed/28401817>
- (78) World Health Organization (2018). Environmental Noise Guidelines for the European Region. http://www.euro.who.int/_data/assets/pdf_file/0008/383921/noise-guidelines-eng.pdf?ua=1