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The effect of wind turbine noise on sleep and quality of life: A systematic review and meta-analysis of observational studies

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ABSTRACT

Noise generated by wind turbines has been reported to affect sleep and quality of life (QOL), but the relationship is unclear. Our objective was to explore the association between wind turbine noise, sleep disturbance and quality of life, using data from published observational studies. We searched Medline, Embase, Global Health and Google Scholar databases. No language restrictions were imposed. Hand searches of bibliography of retrieved full texts were also conducted. The reporting quality of included studies was assessed using the STROBE guidelines. Two reviewers independently determined the eligibility of studies, assessed the quality of included studies, and extracted the data. We included eight studies with a total of 2433 participants. All studies were cross-sectional, and the overall reporting quality was moderate. Meta-analysis of six studies (n = 2364) revealed that the odds of being annoyed is significantly increased by wind turbine noise (OR: 4.08; 95% CI: 2.37 to 7.04; $p < 0.00001$). The odds of sleep disturbance was also significantly increased with greater exposure to wind turbine noise (OR: 2.94; 95% CI: 1.98 to 4.37; $p < 0.00001$). Four studies reported that wind turbine noise significantly interfered with QOL. Further, visual perception of wind turbine generators was associated with greater frequency of reported negative health effects. In conclusion, there is some evidence that exposure to wind turbine noise is associated with increased odds of annoyance and sleep problems. Individual attitudes could influence the type of response to noise from wind turbines. Experimental and observational studies investigating the relationship between wind turbine noise and health are warranted.

1. Introduction

The last few decades have seen governments attempting to decrease greenhouse gas emissions (Olander et al., 2012). This response – to changes in the earth's temperature – has seen the rise of wind power (Leithead, 2007). This alternative energy source, generated by wind turbines, is one tool being employed to generate cleaner energy.

Wind turbine generators (WTGs) are devices that convert wind power into kinetic energy, and are regarded as one of the most important renewable sources of power (Leithead, 2007). Energy generated from WTGs can be used to produce electricity and drive machinery (Caduff et al., 2012; Chang Chien et al., 2011; Li and Chen, 2008). It is thought that large scale utilization of these devices can improve global climate by extracting energy from the atmosphere and altering the pattern of gaseous flow in the earth's atmosphere (Keith et al., 2004).

More recently, exposure to noise from WTGs has been reported to have negative effects on human health (Jeffery et al., 2013). People living near WTGs have reportedly experienced sleep disturbances and a reduction in the quality of life; it has been suggested that a combination of turbine noise, infrasound (sounds with frequency <20 Hz) and ground currents (stray current from electrical equipment which passes through the earth) could be responsible for these symptoms (Havas and Colling, 2011). Cases of litigation because of the unwanted health effects allegedly caused by the noise from WTGs have been reported both in the UK (Daily Mail, 2011) and the US (Oregon Herald, 2013). Very recently, the UK parliament passed a bill restricting the number, height and location of WTGs in England (UK House of Commons Library, 2015).

Studies investigating the effects of wind turbines on sleep and quality of life in individuals living in their proximity have been conducted. While the findings from a pooled meta-analyses of three studies suggested a relationship between exposure to WTG noise and annoyance (Janssen et al., 2011), a more recent review concluded that there was no evidence of a consistent relationship between WTG noise and adverse health effects (Merlin et al., 2013). Therefore, the objective of this systematic review was to explore the association between wind turbine noise, annoyance, sleep and quality of life, and also explore

Abbreviations: WTG, wind turbine generator; ESS, Epworth Sleepiness Scale; PSQI, Pittsburgh Sleep Quality Index.

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the influence of other moderating factors on these outcomes, using data from published observational studies.

2. Methods

We conducted electronic searches in the following databases: Medline, Embase and Global health. Each database was searched from inception till June 2014. MeSH terms used included wind turbine, wind energy, clean energy, annoyance, sleep, and quality of life (a MEDLINE search strategy is included as a web Appendix 1). We also searched Google Scholar for relevant conference proceedings, and hand searched the bibliography of retrieved full texts. An updated search of the databases was conducted on November 28, 2014. Case–control, cross-sectional, and cohort studies were considered for inclusion. To be included in the review, studies had to report annoyance, sleep or quality of life as outcomes in subjects living in proximity with wind turbines. Studies not comparing participants based on the proximity of their homes to WTGs were excluded. No age, language or time restrictions were imposed. Where necessary, contact with study investigators was made to request additional data.

The reporting quality of included studies was evaluated using a checklist adapted from the STROBE (Strengthening of Reporting of Observational Studies in Epidemiology) guidelines (von Elm et al., 2007). Data was systematically extracted by two reviewers [IJO and JOS] using a piloted spreadsheet of pertinent variables including baseline demographics, study location, distances of homes from wind turbines, SPLs, assessment of exposure and outcome. These were independently cross-checked by two other reviewers [MJT and CJH]. Disagreements were resolved through consensus. Our main outcomes were annoyance, sleep disturbance and quality of life (QOL). We also examined the influence of other background noise, visual perception and socio-economic factors on reported outcomes.

Odds ratios (ORs) were used to measure associations between wind turbine noise and annoyance or sleep disturbance. Using the random-effects model of the software for meta-analyses (Review Manager, Version 5.3 (2011)), we calculated the ORs and 95% confidence intervals (CI) for the studies which had sufficient data for statistical pooling. We used sound pressure level (SPL) reference ranges of <40 dB for lower exposure and >40 dB for higher exposure to wind turbine noise in the analyses; these limits correspond to the World Health Organisation (WHO) guideline recommendations for indoor community noise levels suitable for night-time sleep (Berglund et al., 1999). Where SPLs were not available, we used the reported near ("near group") and far ("far group") distances from WTGs for high and low SPLs respectively. Subgroup analyses by SPLs or distances from WTGs were used to test the robustness of overall analyses. Sensitivity analyses by meta-analysing studies with larger sample sizes or with higher respondent rates (≥50%) were used to investigate heterogeneity using the I^2 statistic; values of 25%, 50%, and 75% indicated low, medium, and high statistical heterogeneity respectively. Where statistical combination of reported data was considered inappropriate, such data was reported narratively.

2.1. Definitions

For the purpose of this review, annoyance was defined as a constellation of psychosocial and/or psychological symptoms — "feelings of being bothered, exasperation at being interrupted by noise, and symptoms such as headache, fatigue and irritability" (Anonymous, 1977). Sleep disturbance was defined as any interruption of an individual's normal sleep–wake pattern (Cormier, 1990). A change in an individual's quality of life was measured based on their own perceptions, with regard to their own goals, expectations, standards and concerns (WHO, 1997).

3. Results

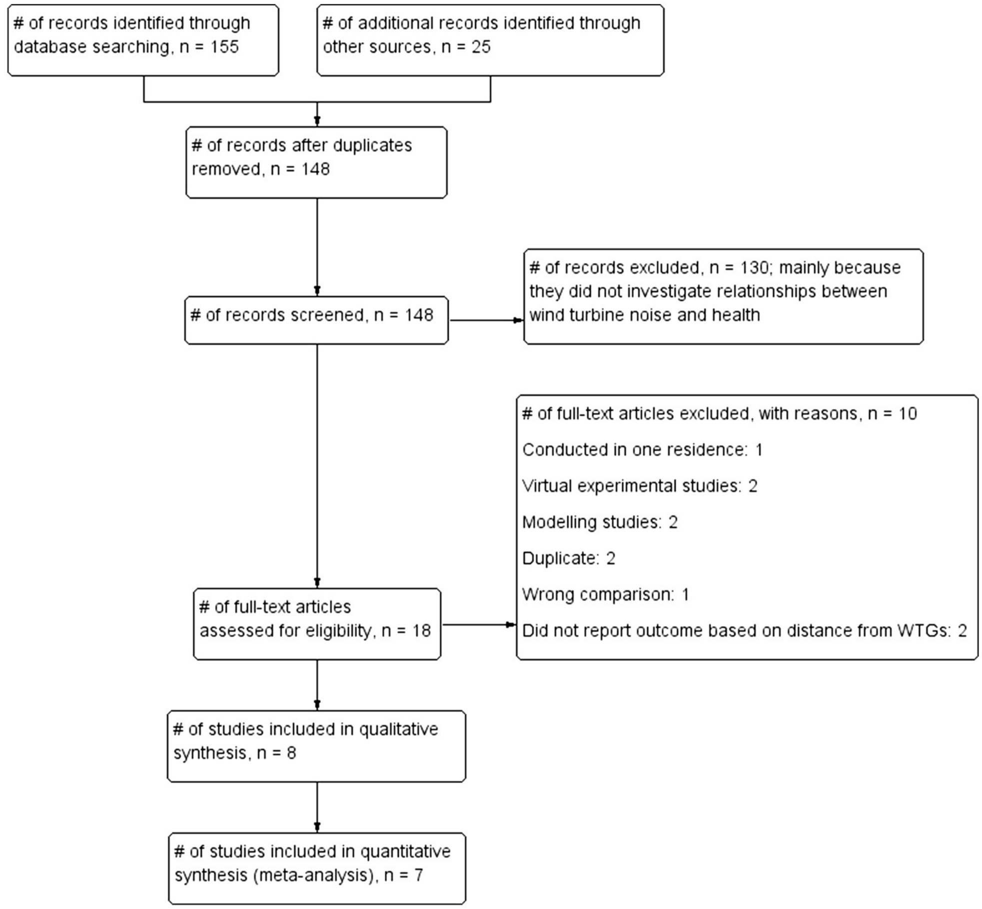
Our electronic searches returned 148 non-duplicate citations, out of which 18 potentially eligible articles were identified (Fig. 1). One article (Ambrose et al., 2012) was excluded because the study was conducted in only one residential apartment and another two (Maffei et al., 2013; Van Renterghem et al., 2013) because they were virtual experimental studies conducted in subjects not residing within the vicinity of WTGs. Two articles (Verheijen et al., 2011; Pedersen and Larsman, 2008) were excluded because they were modelling studies, the latter of which used results from two studies already included in the review. One article was excluded because it explored the effects of road traffic noise using data from a study included in the review (Pedersen et al., 2010) and another two because they did not distinguish subjects by distance from WTGs or SPLs (Harry, 2007; Morris, 2012). Two articles (Nissenbaum et al., 2011; Pedersen et al., 2009) were excluded because more complete versions of their reports were included in the review. Thus eight studies (Bakker et al., 2012; Krogh et al., 2011; Magari et al., 2014; Nissenbaum et al., 2012; Pawlaczyk-Łuszczyńska et al., 2014; Pedersen and Persson Waye, 2004, 2007; Shepherd et al., 2011) with a total of 2433 participants were included in the review. The key details of the studies are shown in Tables 1, 2a and 2b.

All included studies were of cross-sectional design (Table 1). Seven studies reported appropriate recruitment and sampling strategies, and all used objective and validated measures to compute outcome variables. The studies also used appropriate statistical methods to compare groups, but only half (50%) adequately reported sample size calculations. All studies reported adequate statistical analysis, and baseline demographics for participants in the high and low exposure groups were generally similar. The response rate for questionnaires ranged from 37% to 93%.

Annoyance was measured on a 5-point scale (ranging from did not notice to very annoyed) using questionnaires that enquired about attitudes towards wind turbines; one study (Pawlaczyk-Łuszczyńska et al., 2014) used a 6-point scale that included "extremely annoyed" variable after "very annoyed". In all the studies, annoyance from exposure to WTG noise implied being rather annoyed, very annoyed or extremely annoyed. Sleep disturbance (defined in the studies as interruption of normal sleep patterns) was assessed from the general questionnaire administered in seven studies (Bakker et al., 2012; Krogh et al., 2011; Magari et al., 2014; Pawlaczyk-Łuszczyńska et al., 2014; Pedersen and Persson Waye, 2004, 2007; Shepherd et al., 2011), and measured by Pittsburgh Sleep Quality Index (PSQI) in the eighth (Nissenbaum et al., 2012) — this same study assessed daytime sleepiness using the Epworth Sleepiness Scale (ESS). Quality of life was measured in three studies by general health questionnaire (GHQ) (Bakker et al., 2012; Pawlaczyk-Łuszczyńska et al., 2014), short form 36 (SF-36v2) (Nissenbaum et al., 2012), and health-related quality of life (HRQOL) (Shepherd et al., 2011). Two studies used unspecified masked questionnaires that addressed health and general well-being (Pedersen and Persson Waye, 2004, 2007); these questionnaires were described as validated. One study (Krogh et al., 2011) did not use a validated questionnaire to assess quality of life and another (Magari et al., 2014) did not report quality of life as an outcome.

The study locations ranged from rural to semi-rural and metropolitan built-up areas (Table 2a), with varying population densities and terrain. The distance of homes from WTGs varied between 0 and 8 km, and the number of WTGs in the individual studies ranged from 16 to 1846. The emission levels for the WTGs in the studies were measured using A-weighted scales (a filtering method aimed at mimicking responses to sound by the human ear) with 8 m/s downwind, and power generated from the turbines ranged between 0.15 and 2300 kW.

The mean age of the respondents across all the studies was 46 to 58 years (Table 2b). One study (Krogh et al., 2011) did not report the socio-economic status of respondents, while another (Bakker et al.,



The Flow Diagram has been adapted from the online version of the PRISMA statement, 2009. Available from: http:// www.prisma-statement.org/statement.htm

Fig. 1. Flow diagram showing the process for inclusion of studies examining the relationship between wind turbine noise and health.

2012) reported a significantly higher proportion of respondent who received higher education in the high SPL group compared with the low SPL group ($p < 0.001$). The remaining studies did not report significant differences in the baseline demographics of respondents. All the respondents in two studies (Magari et al., 2014; Nissenbaum et al., 2012) had financial benefits from WTGs (Table 2b). Reported background noises

Table 1
Reporting quality of studies exploring the association between turbine noise, sleep and quality of life.

Study ID Country of study	Study design	Appropriate recruitment strategy?	Appropriate sampling technique?	Response rate	Representative sample?	Relevant outcome measures?[a]	Power calculation?	Appropriate statistical analysis?	Evidence of bias?
Bakker et al., 2012 The Netherlands	Cross-sectional	Yes — questionnaire sent to houses	Yes	37%	Yes	Yes	Yes	Yes	No
Krogh et al., 2011 Canada	Cross-sectional	Yes — postal & hand-delivered questionnaire	Unclear	88.9%	Yes	Yes	Unclear	Yes	No
Magari et al., 2014 USA	Cross-sectional	Yes — administered in person by two field personnel	Yes	92.9%	Yes	Yes	Unclear	Yes	No
Nissenbaum et al., 2012 USA	Cross-sectional	Yes — telephone and door to door	Yes	40%	Yes	Yes	Unclear	Yes	No
Pawlaczyk-Łuszczyńska et al., 2014 Poland	Cross-sectional	Yes — postal questionnaire	Yes	71%	Yes	Yes	Yes	Yes	No
Pedersen and Persson Waye, 2004 Sweden	Cross-sectional	Yes — questionnaire sent to houses	Yes	68.4%	Yes	Yes	Yes	Yes	No
Pedersen and Persson Waye, 2007 Sweden	Cross-sectional	Yes — postal questionnaire	Yes	57.6%	Yes	Yes	Yes	Yes	No
Shepherd et al., 2011 New Zealand	Cross sectional	Yes — postal	Yes	33%	Yes	Yes	Unclear	Yes	No

[a] All the outcomes measured were subjective, except for Pedersen and Persson Waye (2007) which measured visual perception using visual angle of WTGs from homes.

Table 2a
Main characteristics of studies investigating the association between wind turbine noise, sleep and quality of life.

Study ID	Study location & site topography	Number of participants	SPLs & distance from WTGs	Power & number of WTGs	Outcomes	Tools used to measure outcomes
Bakker et al. (2012)	1. Rural area (with no major road within 500 m from the closest wind turbine) 2. Rural area with a major road within 500 m from the closest wind turbine 3. More densely populated built up area Flat terrain	725	21–54 dB (average: 35 dB) 0–2.5 km	≥500 kW (0.5 MW); 1846	Annoyance, sleep disturbance, psychological stress	Annoyance: 5-point ordinal scale & 2 Likert scales. Sleep disturbance: Frequency
Krogh et al. (2011)	5 WTG areas with anecdotal reports of adverse health effects	109	0.35–2.4 km	1.65 MW: 5 WTG project areas	Sleep disturbance	WindVOiCe Survey Questionnaire
Magari et al. (2014)	1. Rural area 2. 5 receptor locations within wind turbine park; two locations outside the park as comparator	62	0.4–4 km	1.5 MW; 84	Annoyance, health effects	Validated general questionnaire
Nissenbaum et al. (2012)	2 rural areas — 'low-lying, tree-covered island.' Flat terrain	79	32–57 dB 0.4–6.6 km	1.5 MW; 31	Sleep quality, mental health	Sleep disturbance: PSQI & ESS QOL: (SF-36v2)
Pawlaczyk-Łuszczyńska et al. (2014)	1. 3 populated areas in Central & Northwest Poland 2 Flat terrain 3. Mainly agricultural, but railroads and/or roads also present	156	30–50 dB 0.24–2.5 km	0.15, 1.5 & 2 MW; total number of wind turbines 108	Annoyance, mental health	Annoyance: 5-point ordinal scale Sleep and QOL: GHQ
Pedersen and Persson Waye (2004)	5 wind turbine areas; flat terrain	351	<30 to >40 dB 0.15–1.2 km	14 WTGs: 600–650 kW; 2 WTGs: 150 & 500 kW	Noise perception, annoyance, sleep disturbance	Validated general questionnaire: Annoyance: unipolar annoyance scale Sleep disturbance: presence or absence
Pedersen and Persson Waye (2007)	7 wind turbine areas; different landscapes in terrain and urbanisation (flat and 'complex'–rocky or altitude); suburban and rural	754	31.4–38.2 dB (mean: 33.4). 0.6–1 km (mean: 0.78 km)	>500 kW; 478	Perception, annoyance, sleep quality, quality of life	Validated general questionnaire Annoyance: unipolar annoyance scale Sleep disturbance: presence or absence
Shepherd et al. (2011)	2 semi-rural coastal areas differentiated by their proximity to wind turbines; hilly terrain	197	20–50 dB <2 to 8 km	2300 kW; 66	Annoyance, sleep disturbance, quality of life (health)	Questionnaire with subcomponents: Annoyance: 7-item scale Sleep: 7-item scale QOL: HRQOL

Abbreviations: SPLs: sound pressure levels; WTGs: wind turbine generators; dB: decibels; km: kilometres; kW: kilowatts; MW: megawatts; PSQI: Pittsburgh Sleep Quality Index; ESS: Epworth Sleepiness Scale; QOL: quality of life; GHQ: general health questionnaire; HRQOL: health-related quality of life.

included road traffic noise, noises from birds and household pets, and other machinery.

One study (Pedersen and Persson Waye, 2004) was funded by a grant from a research foundation, while four (Bakker et al., 2012; Magari et al., 2014; Pawlaczyk-Łuszczyńska et al., 2014; Pedersen and Persson Waye, 2007) were funded by government grants. The authors in two studies (Nissenbaum et al., 2012; Shepherd et al., 2011) failed to declare their sources of funding. The authors in all studies were affiliated with public institutions, except in two studies (Magari et al., 2014; Nissenbaum et al., 2012) where authors were affiliated to public health consultancy firms. One study (Krogh et al., 2011) was not funded by any entity.

3.1. Relationship between wind turbine noise and annoyance

Two studies (Krogh et al., 2011; Nissenbaum et al., 2012) did not report annoyance as an outcome. Meta-analysis of the remaining six studies (n = 2364; Fig. 2) revealed a significant increase in the odds of being rather annoyed, annoyed or very annoyed by wind turbine noise (OR: 4.08; 95% CI: 2.37 to 7.04; $I^2 = 63\%$; $p < 0.00001$). Subgroup analyses by SPLs or distance from WTG did not change the direction of the results (Fig. 2). Sensitivity analysis of three studies with larger sample sizes (n = 1793) revealed that the odds of being annoyed by wind turbine noise is significantly increased with higher SPLs (OR: 6.94; 95% CI: 4.36 to 11.03; $I^2 = 10\%$; $p < 0.00001$). Meta-analysis of four studies with higher respondent rates (n = 1313) revealed that the odds of being annoyed by living close to wind turbines is statistically significant (OR: 3.00; 95% CI: 1.87 to 4.80; $I^2 = 0\%$; $p < 0.00001$).

3.2. Relationship between wind turbine noise and sleep disturbance

Two studies (Nissenbaum et al., 2012; Shepherd et al., 2011) did not provide suitable data for statistical pooling. One of these (Nissenbaum et al., 2012) reported the "near group" as having significantly worse sleep scores for both PSQI ($p = 0.046$) and ESS ($p = 0.03$); and two subjects in the "near group" were diagnosed with insomnia compared to none in the "far group". In the second study (Shepherd et al., 2011), participants with greater exposure to WTG noise reported significantly worse sleep scores ($p = 0.0006$). For the remaining six studies which provided suitable data, three (Bakker et al., 2012; Pedersen and Persson Waye, 2004, 2007) used low SPL values of <30 dB as controls, while two (Krogh et al., 2011; Magari et al., 2014) compared groups based on the distances of respondents' from WTGs. Meta-analysis revealed a significant increase in the odds of reporting sleep disturbances with greater exposure to noise from WTGs (OR 2.94; 95% CI: 1.98 to 4.37; $I^2 = 0\%$; $p < 0.00001$; Fig. 3). Subgroup analysis by SPLs or distance did not result in a change in the direction of the results. A similar result was observed when five studies with higher respondents' rates (n = 810) were meta-analysed (OR: 2.76; 95% CI: 1.65 to 4.62; $I^2 = 0\%$; $p = 0.0001$). Sensitivity analyses of studies with larger sample sizes

Table 2b
Demographic characteristics of respondents and influence of moderating factors in the included studies.

Study ID	Mean age	Average duration at home	Socio-economic status	Background noises and their influence on outcome	Visual perception of WTGs and influence on outcome	Financial relationship with WTG and influence on outcome
Bakker et al. (2012)	51 years	Not reported; economic benefits had no statistically significant impact on perception of the sound.	Proportion of respondents with higher education was significantly higher with those living in high SPLs ($p < 0.001$)	Road traffic; aircraft; railways; industry & shunt yards Exposure to WTG sound did not lead to noise annoyance amongst respondents who lived in areas classified as noisy and reported that they could hear the sound. Sound exposure predicted noise annoyance ($r = 0.54$) amongst respondents who reported that they could hear WTG sound and lived in areas classified as quiet	73% of respondents in rural areas and 54% in built-up areas could see at least one WTG from their dwellings The probability of being annoyed by WTG sound was higher if they were visible ($p < 0.001$)	Of 100 persons who benefitted from WTG, 76 were in high SPL group. The proportion of benefiting respondents who were rather or very annoyed by WTG sound was 4 times lower compared to the non-benefiters (12 versus 3%; $p < 0.05$), despite the fact that respondents who benefited economically were exposed to higher levels of WTG sound and noticed the WTG sound more often
Krogh et al. (2011)	52 years	Not reported	Not reported	Not reported	Not reported	Not reported
Magari et al. (2014)	51 years	18 years	Similar for residents	Amongst participants annoyed by WTG noise, 60% were affected daily or a few times weekly by noise, 92% by television or radio interference, and 54% by shadows or reflections None of the indoor or outdoor SPL measurements significantly correlated with other environmental factors — noise, pollution, and landscape littering	On average 19 WTGs were visible General annoyance was significantly correlated with opinion of altered landscape due to WTG ($p < 0.0001$)	All residents benefitted from WTG: substantial property tax reduction; free trash removal Respondents who directly benefitted from WTGs were not less annoyed than other respondents. 90% of participants were satisfied or very satisfied with their environment
Nissenbaum et al. (2012)	57.5 years	14 to 21 years in near group 24 to 30 years in far group	No significant differences	Not reported	WTGs were visible to a majority of respondents The visual impact of WTG on those living closest to turbines was greater compared with those living further away	All residents benefit financially: reduced electricity costs and/or increased tax revenues Fear of reducing property value led to downplaying of adverse health effects
Pawlaczyk-Łuszczyńska et al. (2014)	46 years	Not reported	Comparable between groups	Mainly agricultural terrain with low traffic intensity railways, roads. Did not analyse the impact of terrain and urbanisation on annoyance related to WTG noise. There was high positive correlation between as well as between the respondents' sensitivity to noise and sensitivity to landscape littering ($p < 0.0000001$)	97% of respondents could see 1 or more WTGs from their dwelling, backyard or garden. There was high positive correlation between general attitude towards WTGs and attitude to their visual impact ($p < 0.0000001$)	2.6% benefitted from WTG: type of benefit unspecified
Pedersen and Persson Waye (2004)	48 years	Not reported	No statistically significant differences between groups	Road traffic, rail traffic, neighbours. No significant differences in variables related to noise sensitivity, attitude, or health between the different sound categories At lower sound categories, no respondents were disturbed in their sleep by WTG noise, but 16% of the 128 respondents living at SPLs >35 dB reported sleep disturbance due to WTG noise	WTGs were visible from "many" directions. Respondents' attitude to the visual impact of WTGs on the landscape scenery influenced noise annoyance ($p < 0.001$). No impact of visual perception on sleep disturbance	95% did not own or share a WTG
Pedersen and Persson Waye (2007)	51 years	14 to 16 years in near group 15 to 16 years in far group	Similar for residents	The rural dwellers were the respondents' group with the highest proportion of noise sensitivity (56–59%) There was a significant increase in the odds of annoyance from WTGs in rural areas (quiet) compared with suburban areas (noisy), OR 1.8. [1.25 to 2.51]	The highest proportion of respondents who could see at least 1 WTG was rural (88–91%) Perception of annoyance correlated with SPLs ($p < 0.001$) Both the objective variable "vertical visual angle" and the subjective report of visibility of wind turbines increased the odds of being annoyed: 1.2	Not reported

(continued on next page)

Table 2b (*continued*)

Study ID	Mean age	Average duration at home	Socio-economic status	Background noises and their influence on outcome	Visual perception of WTGs and influence on outcome	Financial relationship with WTG and influence on outcome
					(95% CI: 1.03 to 1.42), and 10.9 (95% CI: 1.46 to 81.92) respectively	
Shepherd et al. (2011)	Range: 18–71 years	Not reported	Matched between groups	No differences between groups for traffic (p = 0.154) or neighbourhood (p = 0.144) noise annoyance	Not reported specifically due to masking of the study intent	Not reported

(n = 838) revealed a significant increase in the odds of sleep disturbances with higher SPLs (OR: 3.24; 95% CI: 2.03 to 5.18; $I^2 = 0\%$; $p < 0.00001$).

Another study (Pedersen and Persson Waye, 2004) reported no statistically significant correlations between sleep quality and sensitivity to WTG noise. One study (Pawlaczyk-Łuszczyńska et al., 2014) reported a significant relationship between the frequency of annoyance and sleep disturbance ($p < 0.05$).

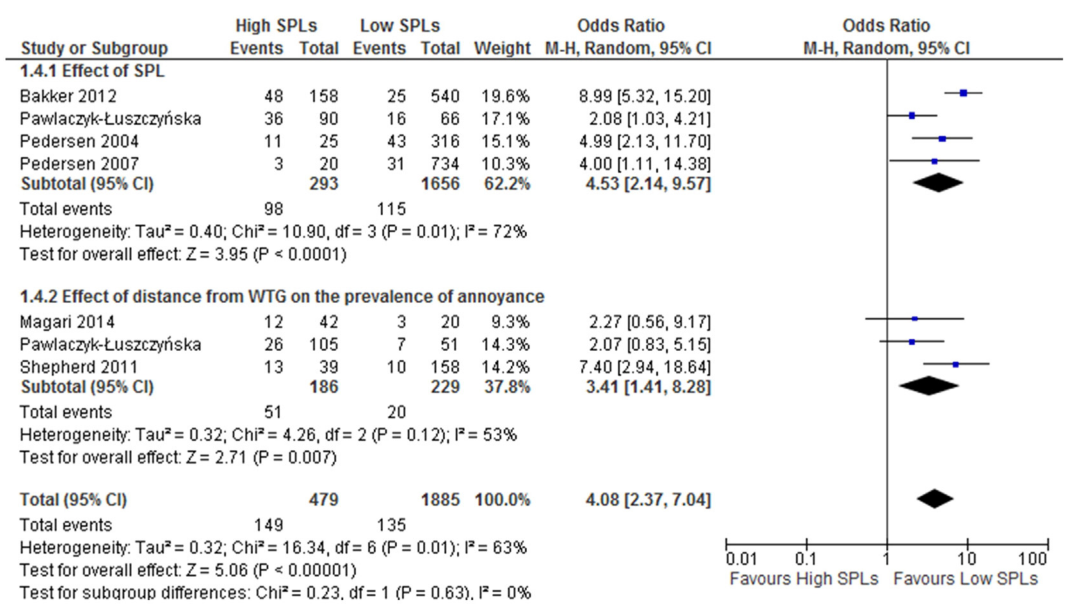
3.3. Relationship between wind turbine noise and quality of life (QOL)

Because of discrepancies in the methods used to assess QOL across studies, a meta-analysis was not considered appropriate. One study (Bakker et al., 2012) reported significant correlations between wind turbine noise and psychological distress in quiet ($p < 0.05$), and both noisy and quiet areas ($p < 0.01$). Another (Nissenbaum et al., 2012) reported that participants in the high noise exposure group had significantly lower QOL (lower GHQ scores) compared with the low exposure group ($p = 0.002$), and a third (Pawlaczyk-Łuszczyńska et al., 2014) reported a weak but significant correlation between wind turbine noise and mental health based on the responses on the GHQ ($p < 0.00625$) — in the same study, a significantly greater proportion of respondents in the "near group" reported that WTG noise has impacted negatively on their health ($p < 0.05$). Another study (Pedersen and Persson Waye, 2007) reported that SPLs were not correlated with general wellbeing of study participants, but annoyed respondents felt significantly more tired ($p = 0.05$) and tense ($p < 0.05$) in the mornings. In one study (Shepherd et al., 2011), the high SPL group had lower HRQOL and environmental QOL scores compared with the lower SPL group ($p = 0.017$ and 0.018 respectively).

One study (Krogh et al., 2011) reported a significant relationship between proximity related WTG noise and excessive tiredness ($p = 0.03$) (the residents in the groups closer to the WTGs reported a higher percentage of excessive tiredness). This same study showed a trend towards increased risk of headache with closer proximity to WTGs ($p = 0.1$). Another study (Nissenbaum et al., 2012) reported a near significant increase in the proportion of respondents receiving new psychotropic prescriptions (after WTG installation) in the "near group" compared with the "far group" (24% vs 0.07 $p = 0.06$). While 90% of participants in one study (Magari et al., 2014) reported being either satisfied or being very satisfied with their environment, the "near group" respondents in another study (Shepherd et al., 2011) were significantly less satisfied compared with the "far group" ($p = 0.03$).

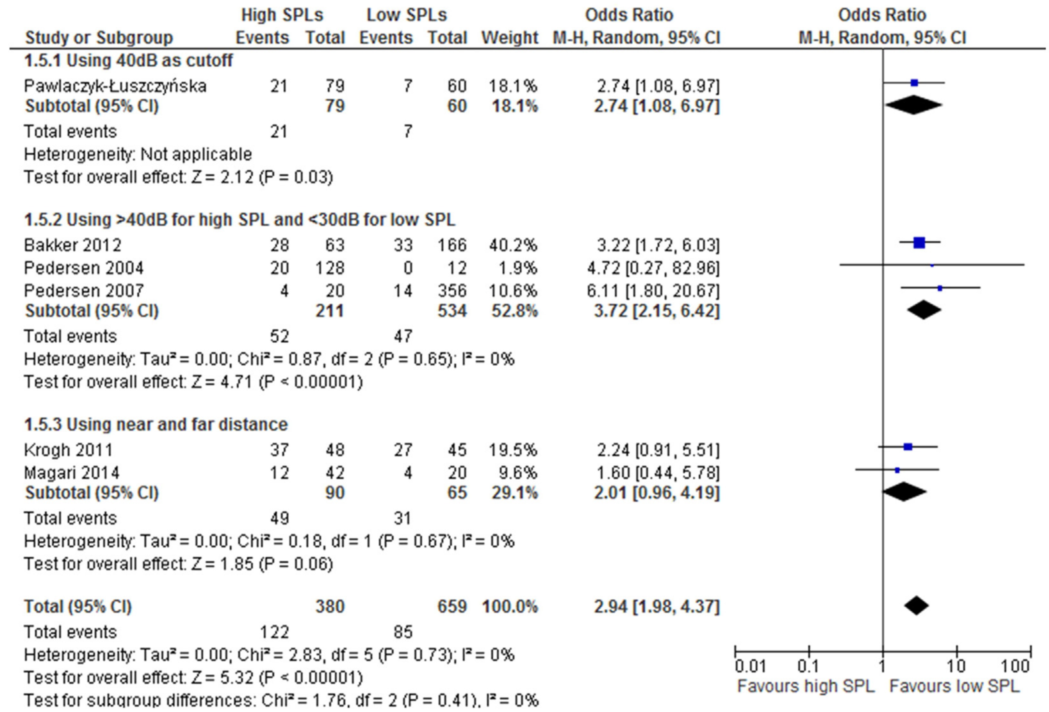
3.4. Influence of background noise and settings on outcomes

In two studies (Bakker et al., 2012; Pedersen and Persson Waye, 2007), episodes of annoyance at a given WTG noise level were significantly higher in quiet areas compared with areas classified as noisy. A third study (Pedersen and Persson Waye, 2004) reported no significant



*Annoyance variable includes "rather annoyed", "annoyed" or "very annoyed". For Magari 2014 and Shepherd 2011, near distances ("high SPLs") are defined as homes located within 2km from the nearest wind turbine generator (WTG); far distances ("low SPLs") were homes located at least 2km from the nearest WTG. For Pawlaczyk-Łuszczyńska 2014, these corresponded to <800m and >800m respectively.

Fig. 2. Relationship between wind turbine noise and annoyance.* *Annoyance variable includes "rather annoyed", "annoyed" or "very annoyed". For Magari et al. (2014) and Shepherd et al. (2011), near distances ("high SPLS") are defined as homes located within 2 km from the nearest wind turbine generator (WTG); far distances ("low SPLS") were homes located at least 2 km from the nearest WTG. For Pawlaczyk-Łuszczyńska et al. (2014), these corresponded to <800 m and >800 m respectively.



*For Magari 2014, near distances ("high SPLs") are defined as homes located within 2km from the nearest WTG; for Krogh 2011, near distances ("high SPLs") were homes located within 700m of the nearest WTG.

Fig. 3. Relationship between wind turbine noise and sleep.* *For Magari et al. (2014), near distances ("high SPLS") are defined as homes located within 2 km from the nearest WTG; for Krogh et al. (2011), near distances ("high SPLS") were homes located within 700 m of the nearest WTG.

difference between groups for different sound categories; however, there was a trend towards increased sleep disturbances with higher SPLs. A fourth study (Shepherd et al., 2011) reported no differences between groups for traffic ($p = 0.15$) or neighbourhood ($p = 0.14$) noise annoyance (Table 2b). One study (Pawlaczyk-Łuszczyńska et al., 2014) did not analyse the impact of other environmental noise on outcomes.

3.5. Effect of visual perception on outcomes

Six studies reported data on the relationship between visual perception of WTG and its influence on outcomes (Table 2b). Five of these (Bakker et al., 2012; Magari et al., 2014; Pawlaczyk-Łuszczyńska et al., 2014; Pedersen and Persson Waye, 2004, 2007) reported a significant positive correlation between visual perception of WTGs and the episodes of annoyance; one of these studies (Pedersen and Persson Waye, 2007) also reported a significant correlation when an objective variable (visual angle) was used to explore the relationship. The sixth study (Nissenbaum et al., 2012) reported that visual impact of WTG on those living closest to turbines was greater compared with those living further away, but did not report whether this was significant. The authors of one study (Shepherd et al., 2011) did not explore the effect of visual perception on outcomes because they wanted to mask the study intent.

3.6. Influence of economic benefit from WTG on outcome

The influence of economic benefit on outcome was inconsistent across the three studies that explored the relationship. One study (Bakker et al., 2012) reported a significantly lower rate of annoyance amongst respondents who benefitted economically from WTGs compared with respondents who had no benefit ($p < 0.001$), while another study (Magari et al., 2014) reported no significant difference in outcomes between groups. Respondents in the third study (Nissenbaum et al., 2012) indicated that the fear of reducing property value led to downplaying of adverse health effects. Two studies (Pawlaczyk-Łuszczyńska et al., 2014; Pedersen and Persson Waye, 2004) in which ≤5% of participants had financial benefits from WTGs did not report whether financial incentives resulted in differences in outcome rates.

4. Discussion

Our results provide evidence that living in areas with WTGs appears to result in "annoyance", and may also be associated with sleep disturbances and decreased quality of life. The results of included studies also suggest that visual perception of WTGs is correlated with increased episodes of annoyance, and the reported adverse effects from WTGs are more prominent in quiet areas compared with noisy ones. The results of our meta-analysis corroborate the findings of a previous meta-analysis of three studies which reported that wind turbine noise is significantly associated with annoyance (Janssen et al., 2011). However, our pooled data contained twice as many studies compared with that report. Our results contradict the findings of another review that concluded that there was no consistent relationship between WTG noise and adverse health effect (Merlin et al., 2013). In contrast to that report, we statistically combined data, and we included evidence from two new studies that were not available for that review. The results of our meta-analysis also support the findings of a more recent systematic review which concluded that exposure to WTG noise increases the risk of annoyance and self-reported sleep disturbance (Schmidt and Klokker, 2014). In comparison with that report, we meta-analysed study data, and also included one study which was not available in that report. Our meta-analyses results should be interpreted with caution due to the variation in outcome measures, and moderate heterogeneity observed in some of the analyses.

The results of our meta-analysis suggest that exposure to WTG noise can elicit annoyance. However, the moderate to large heterogeneity observed in the subgroup analysis limits the firmness of any conclusions that can be drawn from the meta-analytic results. Some authors have suggested that the perception of rhythmic sound pressure by the inner ear could result in negative health outcomes (Enbom and Enbom, 2013; Gohlke et al., 2008; Todd et al., 2008), but this has been refuted by others (Knopper and Ollson, 2011). In addition, other investigators have concluded that it is impossible to distinguish between noises generated by WTGs from that caused by wind itself (Bilski, 2012). Until better tools to assess the impact of WTGs are developed, the relationship between WTG noise and annoyance will remain controversial.

Our meta-analytic results indicate that living close to WTGs increases the odds of experiencing sleep disturbances. Results of studies which did not provide adequate data for statistical pooling were also consistent with this finding. The evidence from the included studies also suggests that sleep disturbance is positively correlated with annoyance and this supports the findings from research conducted in other types of settings (Aasvang et al., 2007; van den Berg et al., 2014; Lee et al., 2011).

We observed a relationship between noise generated from WTGs and reduction in QOL in a majority of the included studies, and this corroborates with previous research reports (Basner et al., 2014; Stansfeld and Matheson, 2003). Pathways showing inter-relationships between annoyance, sleep disturbance and QOL have been modelled (Bakker et al., 2012). However, sleep disturbance has also been shown to independently correlate with a poorer QOL (Lee et al., 2009), and the results of the studies included in our review showed a trend towards a reduction in QOL with increased frequency of sleep disturbances.

It appears that background noise from other environmental sources may influence attitude towards WTGs. The evidence from the studies in our review suggests that the reported adverse effects were more prominent in quiet areas compared with noisy ones. However, residents in quiet areas had a greater proportion of individuals with noise sensitivity and this attitude could have played a role in their responses. Because A-weighted scales (used by most WTGs) totally ignore sound frequencies below 20 Hz, the use of G-weighted scales (specifically designed for infrasound) for measurement of WTG noise has been suggested (Farboud et al., 2013); however, the G-weighted scale has been demonstrated to fluctuate significantly at low frequencies (Bilski, 2012). Other authors have reported that noise from WTGs are too low to cause any harm at distances over 305 m (Knopper and Ollson, 2011; O'Neal et al., 2011). A universally agreed method for measuring sound emissions from WTGs will help clarify these uncertainties.

The results of our review indicate that visual interference could determine attitudes to WTG. There was a greater likelihood of annoyance or less satisfaction if respondents could either see WTGs from their residence, or if they thought WTGs distorted their landscape. This finding supports the conclusions of other authors who reported that visual interference from WTGs may actually be responsible for the annoyance, rather than the noise generated by the wind turbines (Jeffery et al., 2014). Based on this finding, we are less certain if the noise from WTGs themselves actually results in the annoyance, sleep disturbances or reduced quality of life observed in our systematic review and meta-analysis; this issue warrants further investigation.

It is unclear to what extent economic ties with WTGs influenced participants' responses. The inconsistency in the relationship reported across studies makes it difficult to ascertain whether benefitting financially from WTGs affects attitude. Therefore, we are unable to draw conclusions about this relationship based on present evidence.

5. Strengths and limitations

The strengths of this systematic review and meta-analysis are the use of a robust search strategy to identify relevant studies, and our success with obtaining additional data through contact with investigators of studies that we included in the review. The overall quality of the evidence from the included studies was moderate. In addition, heterogeneity was reduced in most of our sensitivity and subgroup analyses, and the results of these analyses were also consistent with overall analyses. However, we recognize some limitations. The small number of included studies prevented us from performing a funnel plot to test for publication bias. It could be argued that publication bias may have occurred in either direction, given the different financial and social implications of WTG and their placement. It is also possible that participants' responses could have been biased; especially in settings where anecdotal reports of adverse effects from WTGs have been documented (Krogh et al., 2011; Magari et al., 2014; Nissenbaum et al., 2012), or in situations where administered questionnaires did not mask the topic of interest (Bakker et al., 2012; Pawlaczyk-Łuszczyńska et al., 2014; Pedersen and Persson Waye, 2004, 2007). It is difficult to gauge the extent to which residual background noise or financial benefits influenced the responses received from study participants. The variations in topography, design, number and power of WTGs, and variation in outcome measures limit the conclusions that could be drawn from our analyses. Finally, apart from one study (Pedersen and Persson Waye, 2007) which used an objective method (visual angle) to assess the relationship between visual perception and annoyance, the response variables measured in the included studies are all subjective and do not establish causality for the relationships examined.

5.1. Implications for research and policy

Independently funded studies exploring the relationships of wind turbines on human health are warranted; in particular, objective outcome measures that separate auditory and visual effects of WTGs should be developed. Experimental and observational studies investigating the relationship between noise exposure at WTGs and health effects should be conducted. Such studies should also explore whether benefitting economically from WTGs influences attitudes. In addition, research aimed at determining the minimum distance of homes from wind turbines at which there will be no risk of interference with health is advocated.

Further, greater monitoring of the sound emission levels from WTGs, especially those located in quiet rural communities, is advocated. A balance between individual and community preferences should be struck when making decisions about where to site WTGs. This will help to ensure the maximisation of the climatic, provider and consumer benefits from future constructions of WTGs.

6. Conclusion

The evidence from cross-sectional studies suggests that exposure to wind turbine noise may be associated with increased frequency of annoyance and sleep problems. Evidence also suggests that living in proximity to WTGs could be associated with changes in the quality of life. Individual attitudes could influence the type of response to noise from WTGs.

Authors' contribution

IJO and JOS were involved with protocol design, data extraction, data-analysis and interpretation, and co-drafting of the manuscript. MJT was involved with data-analysis and interpretation, and co-drafting of the manuscript. CJH was involved with protocol design, data analysis and interpretation, and co-drafting of the manuscript.

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Competing interest

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Appendix A. Supplementary data

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References

Aasvang, G.M., Engdahl, B., Rothschild, K., 2007. Annoyance and self-reported sleep disturbances due to structurally radiated noise from railway tunnels. Appl. Acoust. 68 (9), 970–981 (September).

Ambrose, S.E., Rand, R.W., Krogh, C.E., 2012. Wind turbine acoustic investigation: infrasound and low-frequency noise—a case study. Bull. Sci. Technol. Soc. http://dx.doi.org/10.1177/0270467612455734.

Anonymous, 1977. Noise, annoyance, and mental health. Lancet 1 (8021), 1090–1091 (May 21).

Bakker, R.H., Pedersen, E., van den Berg, G.P., Stewart, R.E., Lok, W., Bouma, J., 2012. Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress. Sci. Total Environ. 425, 42–51 (May 15).

Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., Stansfeld, S., 2014. Auditory and non-auditory effects of noise on health. Lancet 383 (9925), 1325–1332 (Apr 12).

Berglund, B., Lindvall, T., Schwela, D.H., 1999. Guidelines for community noise. Available at:. http://www.bvsde.paho.org/bvsci/i/fulltext/noise/noise.pdf.

Bilski, B., 2012. Factors influencing social perception of investments in the wind power industry with an analysis of influence of the most significant environmental factor — exposure to noise. Pol. J. Environ. Stud. 21 (2), 289–295.

Caduff, M., Huijbregts, M.A., Althaus, H.J., Koehler, A., Hellweg, S., 2012. Wind power electricity: the bigger the turbine, the greener the electricity? Environ. Sci. Technol. 46 (9), 4725–4733. http://dx.doi.org/10.1021/es204108n (May 1, Epub 2012 Apr 20).

Chang Chien, J.R., Tseng, K.C., Yan, B.Y., 2011. Design of a hybrid battery charger system fed by a wind-turbine and photovoltaic power generators. Rev. Sci. Instrum. 82 (3), 035107 (Mar).

Cormier, R.E., 1990. Sleep disturbances. Chapter 77. In: Walker, K., Dallas, W., Hurst, J.W. (Eds.), Clinical Methods: The History, Physical, and Laboratory Examinations, 3rd edition Buttersworth, Boston.

Enbom, H., Enbom, I.M., 2013. Infrasound from wind turbines—an overlooked health hazard. Lakartidningen 110 (32–33), 1388–1389 (Aug 7–20).

Farboud, A., Crunkhorn, R., Trinidade, A., 2013. 'Wind turbine syndrome': fact or fiction? J. Laryngol. Otol. 127, 222–226.

Gohlke, J.M., Hrynkow, S.H., Portier, C.J., 2008. Health, economy, and environment: sustainable energy choices for a nation. Environ. Health Perspect. 116 (6), A236–A237 (Jun).

Harry, A., 2007. Wind turbines, noise and health. February, http://docs.wind-watch.org/wtnoise_health_2007_a_harry.pdf (Accessed 20th November, 2014).

Havas, M., Colling, D., 2011. Wind turbines make waves: why some residents near wind turbines become ill. Bull. Sci. Technol. Soc. 31 (5), 414–426.

Oregon Herald, 2013. Man files $5 million lawsuit for noisy wind turbines. 11th August, Available at:. http://www.oregonherald.com/oregon/local.cfm?id=4327.

Janssen, S.A., Vos, H., Eisses, A.R., Pedersen, E., 2011. A comparison between exposure–response relationships for wind turbine annoyance and annoyance due to other noise sources. J. Acoust. Soc. Am. 130 (6), 3746–3753 (Dec).

Jeffery, R.D., Krogh, C., Horner, B., 2013. Adverse health effects of industrial wind turbines. Can. Fam. Physician 59 (5), 473–475 (May).

Jeffery, R.D., Krogh, C.M., Horner, B., 2014. Industrial wind turbines and adverse health effects. Can. J. Rural Med. 19 (1), 21–26 (Winter).

Keith, D.W., Decarolis, J.F., Denkenberger, D.C., Lenschow, D.H., Malyshev, S.L., Pacala, S., Rasch, P.J., 2004. The influence of large-scale wind power on global climate. Proc. Natl. Acad. Sci. U. S. A. 101 (46), 16115–16120 (Nov 16).

Knopper, L.D., Ollson, C.A., 2011. Health effects and wind turbines: a review of the literature. Environ. Health 10, 78. http://dx.doi.org/10.1186/1476-069X-10-78 (Sep 14).

Krogh, C.M.E., Gillis, L., Kouwen, N., Aramini, J., 2011. WindVOiCe, a self-reporting survey: adverse health effects, industrial wind turbines, and the need for vigilance monitoring. Bull. Sci. Technol. Soc. 31, 334.

Lee, M., Choh, A.C., Demerath, E.W., Knutson, K.L., Duren, D.L., Sherwood, R.J., Sun, S.S., Chumlea, W.M., Towne, B., Siervogel, R.M., Czerwinski, S.A., 2009. Sleep disturbance in relation to health-related quality of life in adults: the Fels Longitudinal Study. J. Nutr. Health Aging 13 (6), 576–583 (Jun).

Lee, S., Kim, K., Choi, W., Lee, S., 2011. Annoyance caused by amplitude modulation of wind turbine noise. Noise Control Eng. J. 59, 38–46.

Leithead, W.E., 2007. Wind energy. Philos. Transact. A Math. Phys. Eng. Sci. 365 (1853), 957–970 (Apr 15).

Li, H., Chen, Z., 2008. Overview of different wind generator systems and their comparisons. IET Renew. Power Gener. 2 (2), 123–138.

Maffei, L., Iachini, T., Masullo, M., Aletta, F., Sorrentino, F., Senese, V.P., Ruotolo, F., 2013. The effects of vision-related aspects on noise perception of wind turbines in quiet areas. Int. J. Environ. Res. Public Health 10 (5), 1681–1697. http://dx.doi.org/10.3390/ijerph10051681 (Apr 26).

Magari, S.R., Smith, C.E., Schiff, M., Rohr, A.C., 2014. Evaluation of community response to wind turbine-related noise in western New York state. Noise Health 16 (71), 228–239 (Jul-Aug).

Merlin, T., Newton, S., Ellery, B., Milverton, J., Farah, C., 2013. Systematic Review of the Human Health Effects of Wind Farms. National Health and Medical Research Council, Canberra.

Morris, M., 2012. 'Waterloo Wind Farm Survey', electronic self-published report. http://www.wind-watch.org/news/wp-content/uploads/2012/07/Waterloo-Wind-Farm-Survey-April-2012-Select-Committee.pdf (Accessed 29th November, 2014).

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

Nissenbaum, M.A., Aramini, J.J., Hanning, C.D., 2012. Effects of industrial wind turbine noise on sleep and health. Noise Health 14 (60), 237–243 (Sep-Oct).

Olander, L.P., Cooley, D.M., Galik, C.S., 2012. The potential role for management of U.S. public lands in greenhouse gas mitigation and climate policy. Environ. Manag. 49 (3), 523–533. http://dx.doi.org/10.1007/s00267-011-9806-1 (Mar).

O'Neal, R.D., Hellweg Jr., R.D., Lampeter, R.M., 2011. Low frequency noise and infrasound from wind turbines. Noise Control Eng. J. 59, 135–157.

Pawlaczyk-Łuszczyńska, M., Dudarewicz, A., Zaborowski, K., Zamojska-Daniszewska, M., Waszkowska, M., 2014. Evaluation of annoyance from the wind turbine noise: a pilot study. Int. J. Occup. Med. Environ. Health 27 (3), 364–388 (Jun).

Pedersen, E., Larsman, P., 2008. The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines. J. Environ. Psychol. 28, 379–389.

Pedersen, E., Persson, Waye K., 2004. Perception and annoyance due to wind turbine noise—a dose–response relationship. J. Acoust. Soc. Am. 116 (6), 3460–3470 (Dec).

Pedersen, E., Persson, Waye K., 2007. Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occup. Environ. Med. 64 (7), 480–486 (Jul).

Pedersen, E., van den Berg, F., Bakker, R., Bouma, J., 2009. Response to noise from modern wind farms in The Netherlands. J. Acoust. Soc. Am. 126 (2), 634–643 (Aug).

Pedersen, E., van den Berg, F., Bakker, R., Bouma, J., 2010. Can road traffic mask sound from wind turbines? Response to wind turbine sound at different levels of road traffic sound. Energy Policy 38, 2520–2527.

Review Manager (RevMan), 2011. [Computer Program]. Version 5.3. The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen.

Schmidt, J.H., Klokker, M., 2014. Health effects related to wind turbine noise exposure: a systematic review. PLoS One 9 (12), e114183 (Dec 4).

Shepherd, D., McBride, D., Welch, D., Dirks, K.N., Hill, E.M., 2011. Evaluating the impact of wind turbine noise on health-related quality of life. Noise Health 13 (54), 333–339 (Sep-Oct).

Stansfeld, S.A., Matheson, M.P., 2003. Noise pollution: non-auditory effects on health. Br. Med. Bull. 68, 243–257.

The Daily Mail UK, 2011. Couple driven out of home by constant hum of wind farm launch landmark battle to get a peaceful night's sleep. 5th July, Available at:, http://www.dailymail.co.uk/news/article-2011162/Wind-farms-whoom-whoom-whoom-noise-drove-mad-farmers-claiming-3m-tell-High-Court.html (Accessed 10th May, 2014).

Todd, N.P., Rosengren, S.M., Colebatch, J.G., 2008. Tuning and sensitivity of the human vestibular system to low-frequency vibration. Neurosci. Lett. 444 (1), 36–41.

UK House of Commons Library, 2015. Planning for onshore wind farms — Commons Library Standard Note. Available at:, http://www.parliament.uk/business/publications/research/briefing-papers/SN04370/planning-for-onshore-wind-farms (Accessed 10th May, 2014).

van den Berg, F., Verhagen, C., Uitenbroek, D., 2014. The relation between scores on noise annoyance and noise disturbed sleep in a public health survey. Int. J. Environ. Res. Public Health 11 (2), 2314–2327 (Feb 21).

Van Renterghem, T., Bockstael, A., De Weirt, V., Botteldooren, D., 2013. Annoyance, detection and recognition of wind turbine noise. Sci. Total Environ. 456–457, 333–345. http://dx.doi.org/10.1016/j.scitotenv.2013.03.095 (Jul 1).

Verheijen, E., Jabben, J., Schreurs, E., Smith, K.B., 2011. Impact of wind turbine noise in The Netherlands. Noise Health 13 (55), 459–463. http://dx.doi.org/10.4103/1463-1741.90331 (Nov-Dec).

von Elm, E., Altman, D.G., Egger, M., Pocock, S.J., Gøtzsche, P.C., et al., 2007. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. PLoS Med. 4 (10), e296. http://dx.doi.org/10.1371/journal.pmed.0040296.

World Health Organization, 1997. Programme on mental health. WHOQOL: measuring quality of life. http://www.who.int/mental_health/media/68.pdf (Accessed 20th May, 2014).