

Wisconsin Wind Siting Health and Policy Review Capstone



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Scope

The scope of this report is defined by our client, Wind Siting Council. Their requirements stipulate that for our literature review; papers included needed to focus on positive or negative health impacts related to wind turbines or siting policies both within the US and abroad, be peer-reviewed, and be written after 2014. Additionally, we are to exclude any papers that discuss the aggregate impacts of renewables, as only papers that look at wind as a discrete impact variable may be considered.

Our methodology for this paper includes completing three search phases (detailed below), summarizing the findings and relevant context of each article, and assigning thematic keywords. We then use the keyword data to analyze and report trends.

Our search phases were conducted as follows:

1. Independent article search: Each team member performed an independent search on the following topics; negative health impacts, positive health impacts and both international and domestic policy.
2. Articles already approved by the council: The Wind Siting Council provided us with a list of articles submitted by members of the council. Following our consideration of papers found in our initial search phases, we identified the most relevant papers on this list, read them, and analyzed them, as with previous papers.
3. Additional article search with topic switch: We performed an additional search to identify any additional articles that would be useful for the Wind Siting Council and switched what topic each team member searched. Subsequently, we reviewed these papers and included relevant publications in our final analysis.

Project Summary

This report details the breadth of topics covered by the 2023 EAP Capstone Team at the direction of the Wisconsin Wind Siting Council. The topics covered center on wind energy as it relates to four primary categories, including: Negative Health Effects, Positive Health Effects, Domestic Policy, and International Policy (Table 1). There are 81 papers considered in this review found over three search phases and including papers recommended by the Wisconsin Wind Siting Council. In addition to these four categories, we also assigned content tags to each paper to describe the specific topics covered. In total, we have 24 tags (Table 1).

Papers addressing negative health effects focused primarily on auditory impacts to health with several also considering visual impacts at different setback distances. Conclusions ranged from inconclusive, to findings of no effect, to findings of some impact to health. It should be noted that the quality of studies related to their findings, where higher quality studies were less apt to find an impact on health. The types of health effects discussed in papers fell into categories of direct or indirect impacts.

Direct impacts are effects that are immediately causal to presence of wind turbines. Indirect impacts are those which are directly causal to an intermediary effect that may have health consequences. Of the direct impacts discussed, one study suggests that wind turbine noise (WTN) can affect heart rate, albeit less than what is caused by air pollution and ambient temperature. Most studies in this section concluded that no

health effects were found or that more research was needed. Papers discussing indirect effects often discuss variables such as visual aesthetics, perceptions of wind energy, and property values are all correlated with health symptoms. For example, annoyance was brought up repeatedly in several studies. Annoyance is not in itself a health effect, however, the impact of wind development on other factors such as sleep disturbance and stress is contested, with different papers coming to different conclusions.

Papers discussing positive health effects centered on the health benefits associated with transitioning from current fossil fuel based energy systems towards wind. The majority of papers in this category discussed indirect health benefits, many monetizing positive health impacts in relation to reductions in air pollution and subsequent reductions in health effects caused by air pollution. Several other papers considered the nature of health benefits rather than their monetary impact.

Policy papers spanned a range of topics but mostly centered on the perception of wind and the impact of policy on wind development. From these papers it becomes clear that the perception of a host community impacts their acceptance of wind development. Acceptance is influenced by the economic impacts of a project, knowledge of wind projects, and community inclusion in development. The impact of policy on wind development cannot be overstated as state-wide policies, particularly siting policies, have a substantial influence on development. Moreover, consideration of stakeholders, openness, and inclusion is considered to be the best way to inform the policy making process.

Table 1. Content Tags Assignments Per Paper Category

Content Tags	All Categories	Health Papers	Policy Papers
Acceptance/rejection	13	1	12
Annoyance	23	21	2
Case studies	9	2	7
Concerns	7	3	5
Confounding variables	2	2	0
Development	18	6	12
Emissions	14	14	1
Impact of policy	4	0	4
Infrasound	6	6	0
Low frequency noise	4	4	0
Monetary benefits	11	10	2
Noise	28	28	0
Perception	20	16	4
Policy recommendations	4	0	4
Physical	6	6	0

Psychological	14	13	2
Review	16	12	5
Safety	1	1	0
Setback	9	6	3
Shadow flicker	5	4	1
Siting process	7	1	7
Sleep	13	13	0
Stress	6	6	0
Visual Impact	4	1	3

Table 1. Depicts the number of papers per category assigned to each content tag. Note that more than one content tag can be applied to any given paper. In addition, some papers fall into more than one primary category.

Differences from the 2014 Report

Upon comparing our findings to the 2014 report's, we found 3 notable discrepancies: 1) while alluded to in the 2014 report, we saw a large amount of literature about intermediary factors between turbines and health effects, particularly annoyance; 2) within policy literature, there was less focus on comparing policies between states and more of a focus on the importance of local involvement in regulation creation; 3) we did not find many opinion-based articles, and while the generalizability of some studies was limited, the vast majority of papers were high quality. That being said, their overall findings were similar to those in the 2014 article.

Regarding intermediary effects, we saw a majority of papers point to annoyance as a factor that impacts the health impacts reported by residents. Beyond this, we found that many papers noted factors influencing the annoyance that people experienced, such as whether or not they felt the siting process was fair, whether they had a financial interest in the development, and their political affiliation.

Furthermore, the policy literature contained one of the largest differences from the 2014 report, as the literature focused more on why policies succeeded or failed rather than on describing the policy landscape. This is likely a result of the changing jurisdictional dynamics among states. The 2014 report stated that "jurisdiction over wind energy developments is held at the state level in 22 cases, the local level in 26 cases, and jointly controlled in two cases." As of a 2020 report from the National Conference of State Legislatures, jurisdiction over development is held at the state level in only 4 states. Joint control is much more common, over 20 states now categorized as being jointly controlled. The rise in literature examining case studies and conducting research where local involvement was done well or poorly is likely tied to this shift toward joint jurisdiction.

Finally, our report found fewer papers based on opinion and of contestable quality. As the number of research papers has substantially increased since 2014, this difference is not surprising. Most of the research we analyzed led to similar findings. We did encounter added nuance regarding how annoyance may be linked to health impacts, as is explained further above. Almost all of the papers we analyzed were conducted in a fashion that minimized researcher bias. Any discrepancies from this trend are noted in the summary document.

Preface: On Article Quality / Limiting Factors

When reading the articles found in our search, we found that the generalizability of their conclusions varied. In studies testing a hypothesis by performing a quantitative analysis, any stated correlation should be statistically significant. This is typically a p-value less than .05. Higher quality studies typically have a larger number of observations or a larger number of participants in their study. Participants in higher quality studies are screened for factors that could potentially affect the results of the study. In higher quality studies using self-reported health effects, researchers make efforts to prevent bias in the answers to the questions. If measuring the health effects or interpreting the self-reported health effects, researchers in higher quality studies also look for other factors or state limitations to their study that could influence their result. As these articles have passed peer review, we assume their methods are legitimate. However, variations in the aforementioned factors can impact the ability to generalize a study's findings and should be taken into account.

Health Effects

Negative

We read 36 papers investigating the potential negative health effects of wind turbines, seven of those papers were literature reviews, four of those papers were responses to other studies or a reanalysis to an already published study. These papers commented on the quality of the study or corrected the analysis of a study and found different results. Three of these papers looked specifically at the Health Canada's Community Noise and Health Study published in 2013. The Health Canada study concluded that the results found in Prince Edward Island and Ontario, wind turbine noise annoyance is associated with self-reported health effects, measured hair cortisol and blood pressure and for other areas wind turbine noise is not correlated to sleep, illness, stress and quality of life. 25 papers were studies looking at various effects of wind turbines on human health. Most papers looked at the effect of noise from wind turbines on human health, and a small number of studies investigated shadow flicker. These studies tested health effects at various setback distances as well.

The structure of the studies varied as well. The studies had various numbers of participants and either formally measured health effects or had participants self-report their health effects. The quality of the study varied when looking at self-reported health effects. Some studies looked to minimize the bias towards wind turbines by disguising the purpose of the study for example Qu & Tsuchiya (2021) used a control group where they did not ask any direct questions on wind turbines. Blanes-Vidal & Schwartz (2016) did not mention wind in their questionnaire and said it was a living conditions study and asked about a variety of factors and symptoms. This impacted the ability for the studies to form conclusions. Some studies were unable to come to a conclusion entirely; some stated in their conclusion that further research needs to be done to make their conclusions stronger; some stated weaknesses and limitations in their study limited its generalizability. Three literature reviews were unable to come to any conclusions because of gaps in research. One literature review by Freiberg, et. al. (2019) commented on the quality of studies found for their review in the conclusion stating; "In higher quality studies, wind turbine noise was not associated with restricted quality of life, sleep disturbance, and anxiety and/or depression, which contrasts— at least partly — with findings from lower-quality studies."

Direct

Most negative health effect studies investigated the negative health effects on humans from wind turbine noise. Three studies found a health effect from wind turbine noise. The health effects were heart rate variation, sleep disturbance, stress and other physiological conditions. For instance, Chiu, et. al. (2021) concluded that in addition to wind turbine noise affecting heart rate variation from a radius of 500m away, PM2.5 pollution and ambient temperature has a greater effect on heart rate variation. This study also discussed setback regulation in Taiwan.

Contrastingly, five studies did not find any evidence of a health effect related to wind turbines. A literature review by van Kamp, et. al. (2021) found that there needs to be more research on wind turbine noise and sleep disturbance, but concluded there is not a correlation between wind turbine noise and mental health or metabolic effects. Qu, et. al. (2021) found that noise from wind turbines is correlated with health concerns (headaches and nausea). However, there were other factors that affected the participants' self-reported health in the study such as their view of wind energy and noise sensitivity. A study by Poulsen, et. al. (2018) stated that very high exposure *could* have minor impacts on preterm birth, gestational age, or low term birth weight. Poulsen et. al (2019). found a small non-statistically-significant increase in myocardial infarction risk due to turbine noise and no associations with stroke.

Indirect

Most studies researching the potential negative health effects of wind turbines examined the direct impacts of wind turbines on human health. However, some papers concluded some indirect effects on human health. In four studies, researchers found that wind turbine noise or shadow flicker causes annoyance but were not able to conclude that there were any health effects from wind turbines. In Michaud et. al.'s paper "Exposure to wind turbine noise" (2016), researchers found that "annoyance toward all features related to wind turbines, including noise, vibrations, shadow flicker, aircraft warning lights and the visual impact, increased as WTN levels increased." Another study by Hübner, et. al. (2019) that linked wind turbine shadow flicker to annoyance found that only 1.1% of their study participants in the United States were strongly annoyed by wind turbines. Radun, et. al. (2022) found that the only health effect from wind turbine noise is annoyance and stated that traffic noise was associated with a higher probability of self-reported health effects. Another study by Pohl, et. al. (2018) also looked at residents living in the proximity to wind turbines in relation to traffic noise and found that residents are more annoyed by traffic noise.

Three studies found that there are confounding variables that lead to health symptoms. These variables are visual aesthetics of wind turbines, perceptions of wind energy, and property values in relation to wind turbines in proximity. These studies concluded that the participants' sleep disturbances and other health symptoms were correlated to these variables. Two studies did not draw a definitive conclusion but stated that there were likely confounding variables. Tonin, et. al.'s 2016 study stated that "It appears that self-reported sleep reported of participants may be associated to the indirect effects of visual and attitudinal cue and concern about property devaluation rather than distance to the nearest WTs or noise as itself. However, firm conclusions are not possible due to the discussed limitations." Two studies and 1 review of a study found annoyance from wind turbines leads to health effects, such as stress. The literature review by Karasmanaki, et. al. (2022) found that annoyance is affected by other beliefs and

cited that distance from the turbines can determine symptoms as well. The Health Canada Summary of results (2014) study stated that, while their results were specific to the location of the study and further research needs to be done to verify these results, they found no correlation between wind turbine noise and health effects. They only found a correlation to annoyance and found annoyance to be associated with self-reported health effects.

Positive

Of the papers we read, a total of 21 discussed potential positive health impacts of wind turbines. Regarding positive health effects, most of the discussion centers around indirect effects, namely: avoided effects resulting from the transition from fossil fuels to wind power. The general consensus surrounding these indirect effects is that switching to wind power from fossil fuels provides significant human health benefits. Details regarding this consensus are discussed in the *Direct* and *Indirect* sections.

Direct

Given the nature of wind turbines, almost no papers detail direct positive health impacts. We only examined perception as it relates to health and siting policy, so this claim should not be confused with stating that no studies detailed individuals as feeling positively toward turbines. Given the limits of our review, only when feelings were tied to tangible health outcomes or to policies were they considered.

One study by Crichton, et. al. (2014) alluded to potential positive psychological effects for those who had been positively primed and exposed to wind turbine noise. The study found the same effect in the negative, and thus the study was formally categorized in the *Positive & Negative* tag.

Indirect

The majority of papers on positive health impacts looked at indirect benefits. Nine papers directly monetized positive health impacts from switching to wind power (from coal or another fossil fuel). In these papers, reductions of pollutants SO₂, NO_x, PM_{2.5}, and CO₂ were identified as the most impactful on the health benefits of transitioning to wind. Where benefits were monetized, papers took a variety of different approaches. Those that delineated between regions (Siler-Evans, et. al. (2013); Buonocore, et. al. (2019); Buonocore, et. al. (2015)) likely provide a more accurate picture of Wisconsin's potential benefits. The studies also varied in their units of measurement. Some studies measured benefits over a range over years or a year period, and others examined benefits per kilowatt hour of energy produced. Thus, the studies' monetary estimates vary and, if one wanted to compare them, significant care would need to be taken to ensure the units of measure were properly converted. Of the papers that monetized the health impacts of transitioning to more wind power from fossil fuels, all reported significant net benefits.

Several papers did not monetize health benefits explicitly but researched the nature of the health benefits gained by transitioning to wind. Buonocore, et. al. (2016) noted that health benefits of offshore installations increase with the magnitude of the installation. Adeyeye, Ijumba, & Colton (2020) reviewed literature surrounding the factors that would impact a cost-benefit analysis of wind installations and noted that even when examining potential noise and visual impacts of turbines, wind produced significant net positive health impacts.

While two studies - Wiser, et. al. (2020) and Novan (2015) - recommended diverse energy portfolios where wind is not the only source of energy, all of the studies noted that an increase from current levels of wind energy would produce benefits to human health.

Positive & Negative

Some articles *focused* on both positive and negative potential effects or examined more neutral effects overall. Of the papers we read, we determined that six of them fell into this category.

Two papers examined human's ability to recognize certain noises and are useful as supplementary materials when examining articles on turbine noise. Maffei, et.al (2015) concluded that individuals were less able to recognize wind turbine noise as distance from the noise increased. Berger, et.al. (2015) measured infrasound levels from turbines at various distances. At 450 m, infrasound was determined to be imperceptible to humans.

One life cycle analysis (Li, Li, & Wu 2020) fell into the *Positive & Negative* category, as it calculated the total carbon emissions from all phases of a wind site's life (production, transportation, construction, operation, and end-of-life) and compared their calculations to those of other energy sources, namely fossil fuels. Ultimately, it found that wind sites had much lower carbon emissions throughout their life cycles.

Crichton, et. al. (2014), as briefly mentioned in the *Direct Positive* category, found that priming individuals on the potential health benefits or detriments significantly impacted their symptoms when exposed to wind turbine noise.

One study, Baxter, et. al. (2013), detailed how perceptions of health benefits or detriments were associated with the distances individuals lived from turbine sites. They found that the further individuals were living from turbine sites, the more they were concerned about their health impacts. Similarly, Songsore, et. al. (2016) researched the media coverage of wind siting and found that most coverage focused on negative health impacts of siting, potentially influencing perception by the public. While both of these papers fall outside the realm of tangible health outcomes resulting from turbines, we included them as they directly relate to health outcomes. Thus, they should be considered supplementary to the aforementioned findings.

Policy

Domestic

The share of electricity generated from renewable energy sources is expected to double by 2050, with growth largely attributed to developments in solar and wind energy (EIA, 2019). With the rise in wind development, national, state, and local governments are increasingly defining their relationship with wind development through policy. Of 23 policy papers considered in this report, nine covered domestic policy issues. These papers spanned a breadth of topics, but seven papers could be broadly categorized as pertaining to either (1) policy impacts or (2) perception of wind.

Perception of Wind

Perception remains an important topic among research and discussions centered on wind development. While the determinants of perception are multifaceted, there is evidence that socioeconomic impacts may be an influence. An examination of papers published in North America suggests that annoyance and opposition to wind turbines is linked to their sound and visual impacts, while acceptance of wind turbines is correlated with their socioeconomic impacts (Rand et. al, 2017). With that in mind, the authors suggest that the acceptance of wind-energy development can be bolstered by considering fairness, participation, and trust, without ignoring known impacts. A small study surveying residents living in close proximity of wind turbines found that a subset of locals without monetary ties to wind development were more likely to believe adverse health effects were connected to the site (Krogh et.al, 2020). The link to financial benefits and perception of wind (Wolske et. al, 2019; Krogh et.al, 2020). has been noted in several studies in different locations Another small survey study observed that locals in close proximity of wind turbines were mostly positive and suggest that providing knowledge of the impacts of wind energy development to communities may reduce opposition to wind projects (Pavlowsky et. al, 2021).

Policy Impacts

The impact of policies at different levels of government hold varying levels of influence over a given wind development project. Best exhibited by Schumacher & Yang (2018), wind capacity and wind energy penetration are more impacted by state-wide siting and permitting processes related to environmental regulations than demographic and geospatial factors (Schumacher & Yang, 2018). Siting policies are of particular note as they determine the specifications and requirements of development in a given area. Some studies indicate that restrictions in siting have an impact on future wind-turbine development and that they have a greater impact in a resource-constrained environment (Mai et. al, 2018). The development and implementation of such policies involves the consideration of multiple stakeholders. One study found that as policy makers gain experience with wind developers, they are more apt to implement wind ordinances, but that experience has no effect on the stringency of regulations (Lerner, 2021).

International

International policy papers considered in this review draw from a variety of countries, including: Australia, Austria, Canada, Denmark, Germany, Ireland, Israel, Italy, Sweden, Switzerland, and multiple countries. There are 14 papers total, with three papers focusing on Canada and two review papers covering multiple countries. Of these 14 papers, 11 papers could be broadly categorized as pertaining to either centering on (1) policy impacts or (2) perception of wind.

Perception of Wind

The success of wind projects is dependent on many factors, but does rely in part on the acceptance of host communities. Some factors that can inform acceptance relate to demographic factors. For example, a Swedish study indicated that the likelihood of rejection is higher in areas associated with higher levels of education and private sector employment and that the likelihood of approval is higher in areas with more unemployed people (Liljenfeldt & Pettersson, 2017). Another finding, based in Swiss

case studies, suggested that project siting success can depend on policy beliefs and advocacy coalitions (Blake et. al, 2020).

Identifying the concerns of host communities is another relevant area of study to wind development. A review of Environmental Assessments in Canada revealed that nearly 80% of concerns regarding wind development surrounded land use, impacts on human well-being, impacts on natural ecosystems, and economic opportunity (Dutta et. al, 2020). An Australian study revealed that health impacts are a primary concern for those living near wind developments and are not a proxy for other land use concerns (Botterill & Cockfield, 2016). Yet another perspective to consider is that of concerns implied through existing development policies. For example, a German study that found current turbine placement already considers cost-efficiency, landscape impact, and distance from the grid in an analysis of 160,000 wind turbines (Weinand et. al, 2022).

Aside from the concerns of the public, there is evidence that the representation of these issues in Canadian news articles tends to be negative. More specifically, Deignan & Hoffman-Goetz (2015) found that over 99% of news articles in their review had a negative tone, and that articles were more likely to mention health generally rather than cite specific health impacts.

Policy Impacts

There is much discussion surrounding what development and policy ought to look like. For better outcomes, some studies suggest that the communities need to be considered as individuals. For example, one study suggests that meeting community needs and developing benefits should consider multiple dimensions by wind developers and systems operators, while another suggests “establishing trust in authorities by engaging with community values empowers affected communities” (Sardaro et. al, 2019; Borch, 2018). Another key point in this literature is an emphasis on openness in both the policy making process and in conflict resolution (Borch, 2018; Kapeller & Biegelbauer, 2020). Yet another recommendation considers the impact of perception on project outcomes, suggesting proactive media strategies to “help reduce the impact of negative coverage” (Borch, 2018).

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