Wind Power and Human Health

FLICKER, NOISE AND AIR QUALITY

WEST MICHIGAN WIND ASSESSMENT ISSUE BRIEF #2

The West Michigan Wind Assessment is a Michigan Sea Grant-funded project analyzing the benefits and challenges of developing utility-scale wind energy in coastal West Michigan.

More information about the project, including a wind energy glossary can be found at the web site, www.gvsu.edu/wind.

- *As the number of wind farms increases, people have become concerned about possible health effects, particularly from wind turbine sounds.*

In 2008, Michigan passed a Renewable Portfolio Standard, which requires that electricity providers generate at least 10% of their electricity from renewable sources by 2015. Michigan's utility companies consider wind energy to be the most cost-effective, scalable means of meeting this target [1]. Wind power has the potential to reduce Michigan's reliance on fossil fuels such as coal, and thus could offer many benefits for people and the environment. However, all forms of electricity generation have some impact. In this issue brief, we summarize the available science about how onshore wind farms might affect human health, with the goal of helping communities anticipate, evaluate and manage their development options. Three issues are examined: the potential negative impacts of wind turbine shadow flicker and noise, and the potential benefits of improved air quality.

Wind Turbine Flicker

Shadow flicker occurs when the sun is low in the sky and a wind turbine creates a shadow on a building (Figure 1). As the turbine blades pass in front of the sun, a shadow moves across the landscape, appearing to flick on and off as the turbine rotates. The location of the turbine shadow varies by time of day and season and usually only falls on a single building for a few minutes of a day. Shadows that fall on a home may be disruptive. Shadow flicker has been a concern in Northern Europe where the high latitude and low sun angle exacerbate the effect [2]. However, flicker has rarely been cited as a problem around the commercial wind farms in Michigan's Thumb Area (T. Groth– MSU graduate researcher, personal communication).

- *Wind turbines can create a flickering shadow when the sun is low in sky and just behind a rotating turbine.*

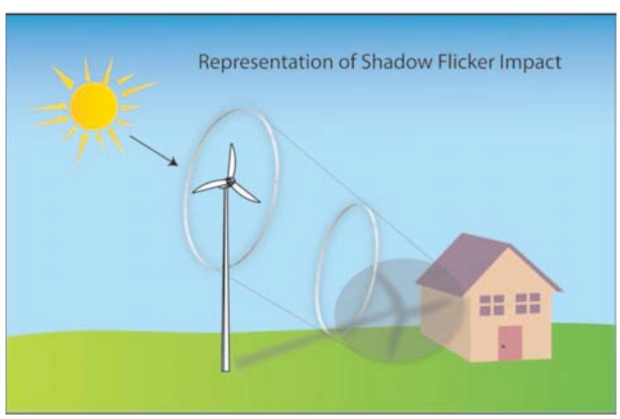

Figure 1: Turbines can cause a flickering shadow on buildings during certain periods of the day. *(American Wind Energy Assoc.)*

- *The flicker effect is a concern for people who suffer from photosensitive epilepsy and experience seizures in response to certain environmental triggers.*

- *Ottawa County's model ordinance mandates that shadow flicker on a home not exceed 30 hours per year.*

- *Forty-one of the 73 townships in study area have some kind of wind power ordinance. Of these, 21 specifically address flicker effect.*

The flicker effect is a particular concern for people who suffer from photosensitive epilepsy and experience seizures in response to certain environmental triggers. Photosensitive epilepsy is a relatively rare condition, affecting about one in 4,000 people. A variety of stimuli can induce a seizure in sensitive individuals, including sunlight reflecting off waves, the intermittent shadows along a tree-lined street, a television, or flicker from fast-rotating wind turbine blades. Medical research has shown that a flicker rate of three flashes per second (120 per minute) or slower has a very low risk of inducing a seizure in sensitive individuals. It is now standard practice in television to avoid sequences with a flicker greater than three flashes per second. Guidelines for wind farm development also recommend a flicker rate of no more than three per second [3]. On a typical three-bladed wind turbine, this would correspond to a rotation speed of one complete rotation per second (or 60 rpm). A modern utility scale wind turbine rotates at a much slower rate. For example, the Fuhrländer FL 2500 turbine rotates at about 17 to 20 rpm and the Clipper Liberty 2.5 MW turbine rotates about 10-15 rpm. The flickering shadow of modern, utility-scale turbines should not be fast enough to trigger seizures.

Shadow flicker can be addressed in a variety of ways, including landscaping to block the shadows or stopping the turbines during the sensitive times. Many municipalities regulate the amount of wind turbine flicker through zoning ordinances. For example, Ottawa County has issued a model wind ordinance that local governments can choose to adopt or modify. The model ordinance requires wind turbine owners to analyze shadow flicker to determine where the shadows would fall and for how long over the course of one year. It also mandates that shadow flicker on an occupied building not exceed 30 hours per year [4]. Forty-one of the 73 townships in the four-county study area have some kind of wind power ordinance. Of these, 21 specifically address wind turbine flicker (Figure 2). The existing ordinances range from simply stating that flicker analysis may be requested to zero tolerance for flicker on or in any dwelling.

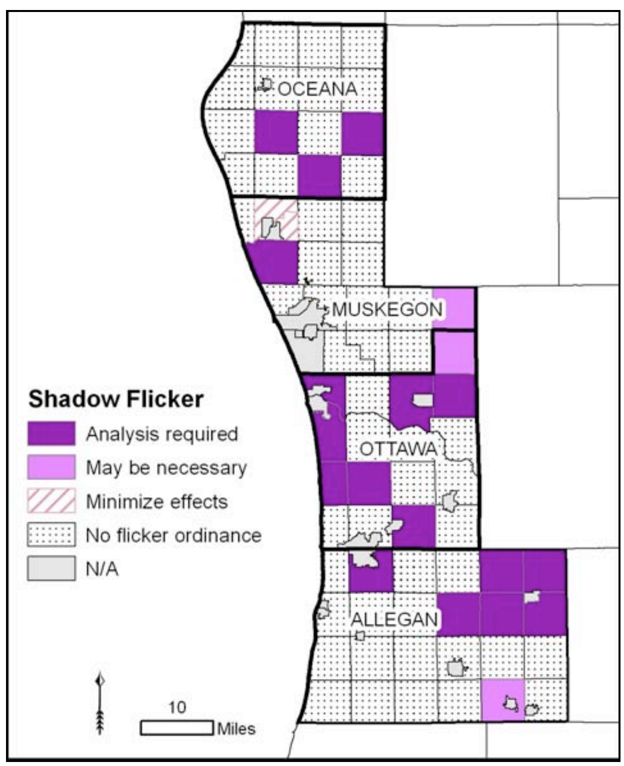

Figure 2. Shadow flicker specifications in township wind ordinances in the study region of west Michigan.

Wind Turbine Sounds

Many West Michigan residents are also concerned about the noise of wind turbines. Despite many design improvements for modern turbines, noise and public perception of noise are still important considerations when siting wind turbines. Wind farms are often located in relatively quiet, rural settings where there is less tolerance for noise. The next three sections provide a review of the many studies evaluating sound emissions from wind farms and people's reactions to the noise.

- *As each rotating blade passes in front of the tower, air turbulence produces a characteristic swoosh- swoosh sound.*

Sounds from a wind turbine originate from both the mechanical components and the blade aerodynamics. The rotating mechanical parts in the nacelle of the turbine (at the top of the tower) produce a characteristic hum that is relatively constant in pitch and strength. Airflow across the rotating blades produces sounds across a wide swath of the sound spectrum (broadband noise). The sound gets louder as each blade passes in front of the tower, creating the swoosh sound often associated with wind turbines.

Scientists measure a sound's loudness in decibels (dB). A common variant of that measure is the A-weighted decibel scale (dB(A)), which under-weights low and high pitch sounds and therefore more closely matches how the human ear perceives sound [5]. A sound's pitch is typically measured in hertz (Hz), which describes the frequency or cycles per second. Lower pitches have lower frequencies, like the keys on the left side of a piano. Pitch and loudness are independent of one another. For example the low pitch piano keys may be played softly (low dB) or loudly (high dB).

- *A single, modern, utility scale wind turbine produces sounds at about the same loudness as a normal conversation (50 – 60 dB(A)) when standing within 100 feet of the base.*

The level of noise produced by a wind turbine depends on its design, wind speed and how sound travels across the landscape. Noise from the blades generally increases as they rotate faster, although high wind speeds may mask turbine noise [2, 5]. Nearly all modern utility turbines have designs that minimize noise, including upwind rotors, variable pitch and insulation in their nacelles, and many can vary their rotational speed. The blade tips of large utility turbines actually rotate more slowly and generate less noise than small turbines [6]. In the US, all wind turbine manufacturers must measure and report turbine sounds following standards set by the International Electrotechnical Commission, which must include sound pressure levels and dominant frequencies (such as a whistle) at five different wind speeds for a specific turbine model. Specific measurements for infrasound are optional within the current standards (IEC 61400-11).

The Stoney Corners Wind Farm in McBain, Michigan uses a 2.5MW wind turbine called the Fuhrländer FL 2500. This new, large turbine model produces a sound pressure level of 105.1 dB(A) at the rotor, but the noise level consistently diminishes as distance from the turbine increases (Figure 3). A person standing within 100 feet of the base of an active turbine would experience an average sound pressure level of 56 dB(A), about the same loudness as a normal conversation. The sound at 1000 feet would be about 45 dB(A), similar to the background noise level in an average suburb. These sound estimates are consistent with other wind farms, as reviewed by the National Research Council committee on wind energy [2].

As sound travels away from at wind turbine the sound strength degrades in a predictable way, allowing engineers to model noise levels using a standard equation.[1] The simple sound propagation model presented in Figure 3 accounts for

[1] $L_p = L_w - 10\log10\,(2\pi R^2) - aR$; where L_p is the sound power level at the source (dB), L_w is the sound pressure level at the receptor (dB), R is the distance from the source (m), and a is an estimate of the atmosphere's sound absorption capacity (0.005 dB/m) [22].

atmospheric absorption of sound, but does not account for terrain, ground absorption or wind direction. Actual landscape features may block or funnel sounds and may increase or decrease the perceived sound at a particular location. Acoustic engineers can perform site-specific noise evaluations in advance of a wind energy development.

- *The sum of two turbines equally close to a home will only produce 3 decibels more sound than single turbine.*

The next logical question might be, how much noise will multiple turbines in a wind farm produce? Sound levels from multiple sources cannot be merely added together in a linear fashion – the sum of two sounds depends on the difference between the two sound strengths. If two sounds differ by more than 10 decibels, the quieter of the two sounds adds only a fraction of a decibel to the louder sound. For example, the noise from a turbine 1500 feet away (40 dB) will add only a minor amount of sound (0.4 dB) to the levels produced by a turbine 500 feet away (50 dB). If two sounds are identical, as would happen if two turbines are equally close to a home, the combined sound will be 3 decibels higher than just one turbine [7]. Therefore, the arrangement of turbines will affect overall sound levels, but the combined effect may be only somewhat louder than a single turbine.

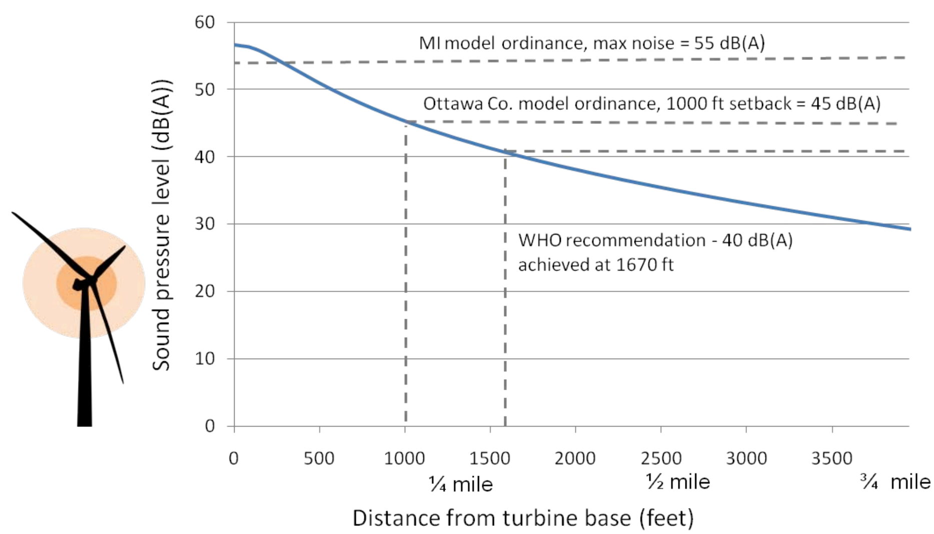

Figure 3. Estimated noise levels at different distances from a 2.5MW turbine, similar to the one in use at the Stoney Corners Wind Farm in McBain, MI (Fuhrländer FL 2500). At the top of the 325 foot tower, the turbine produces 105.1 dB(A) of sound.

- *Nighttime noise levels between 40 and 55 dB can disturb sleep and exacerbate hypertension for children, the chronically ill and the elderly.*

Evaluating Noise Levels

The next two sections provide some context for evaluating turbine sound levels, by 1) comparing it to everyday noises and environmental noise regulations, and 2) reviewing the available research about how wind farm noise is perceived by neighboring residents.

The National Institute for Occupational Safety and Health's guidelines state that long-term exposure to sounds greater than 85 dB leads to increased risk of hearing loss [8]. Studies of airport noise reveal that lower levels of environmental noise, especially nighttime noise, can also cause health problems by interfering with sleep and raising blood pressure of sensitive individuals [9]. The Federal Aviation Administration (FAA) uses noise limit of 65 dB, which the agency states is the level where about 25 percent of residents are extremely annoyed by aircraft.

- *Noise will also be created by wind farms during construction and repair times and from electricity transmission facilities.*

- *Many wind ordinances mandate that turbines be more than 1000 feet from homes. At this distance the loudness would be similar to suburban street noise.*

The World Health Organization (WHO) recently reviewed all the evidence that relatively low levels of nighttime noise could impact human health [10]. They found that nighttime noise greater than 55 dB, as measured just outside a home, can cause sleep disturbance and annoyance for a "sizeable proportion of the population" and "there is evidence that the risk of cardiovascular disease increases". The WHO recommends limiting nighttime noise levels to 40dB outside of homes to avoid the potential health effects associated with sleep disruption and protect vulnerable populations – such as children, the chronically ill and the elderly [10, p. XVII].

Sounds from modern utility wind turbines are well below the levels that could cause direct physical harm, such as hearing loss (Figure 4). However, to keep turbine noise within the nighttime guidelines recommended by WHO (40 dB) communities would need to maintain more than a 1000-foot setback between wind turbines and any residences.

In addition to the noise of wind turbine operation, most wind farms require a substation and high voltage transmissions lines, which produce a characteristic hum and crackle. Utility companies have experience building and siting these facilities to minimize their impact. The construction of a wind farm will also create substantial noise and traffic for a period of time. Some projects have documented a U-shaped acceptance curve where public acceptance is high during the initial phase, decreases during the construction phase, and increases once operation begins [11].

It would be helpful to contrast the noise of a wind farm with the noise from a coal-fired power plant throughout the entire life cycle of energy production, including construction of the energy facility, mining and transport of fuel, operation, on-going maintenance, and eventual deconstruction of the facility. All of these steps involve some level of noise; however, comparable data were not available [12].

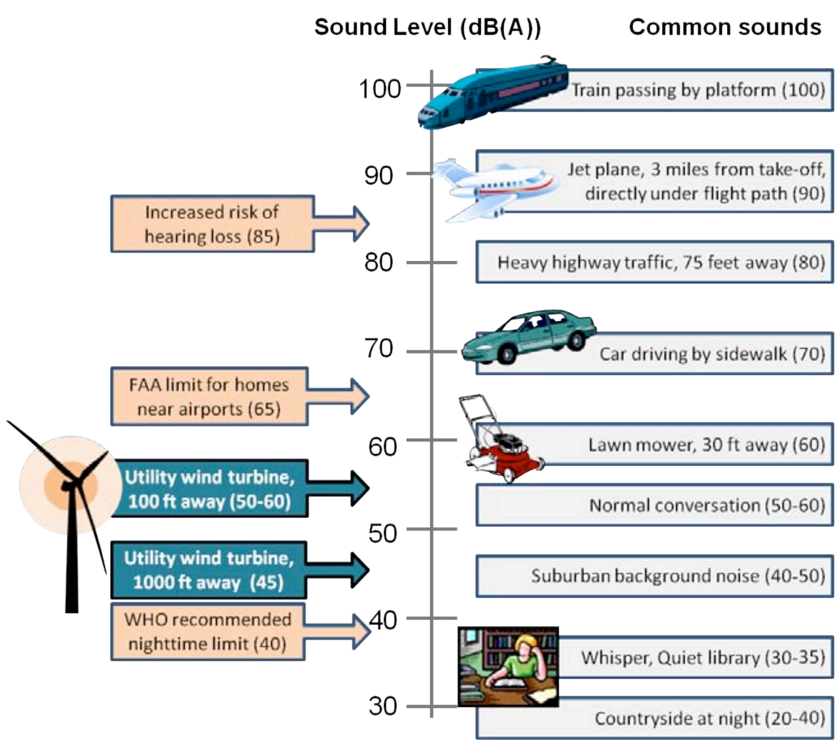

Figure 4. Sound magnitude levels associated with everyday sounds in A-weighted decibels (dB(A)), the units commonly used to describe and regulate environmental noise [7]. Turbine sound estimates are explained in Figure 3.

Human Perception of Noise

- *The level of annoyance with turbine noise was higher than that reported for other transportation noise of the same loudness.*

Noise is defined simply as any unwanted sound, but our reaction to sound is complex and has physical, psychological, spatial and temporal dimensions. Decibels only measure a sound's loudness or magnitude. The relative unpleasantness of a sound is a subjective matter and often depends on the person and the context, such as the time of day and the mix of other sounds in the environment.

Environmental health scientists have found that relatively few people (less than 10 percent) report being disturbed by noise from air, road and rail traffic at levels less than 45 dB(A) [12]. People encounter these sources of noise every day and have likely grown accustomed to them. Recent studies show that people are more bothered by the swooshing of wind turbines than other transportation noise of the same loudness [13]. However, wind turbines are a relatively new development in most places and people's perception of them may change over time.

- *In a survey of more than 1,000 residents living close to wind turbines, the large majority of respondents either did not notice the noise or noticed it but were not annoyed.*

When discussing attitudes towards wind turbine noise, people often cite a series of studies completed in Sweden between 2004 and 2008 [13, 14, 15]. During two studies, researchers surveyed 1095 residents in 12 areas with utility-scale wind turbines and then combined the results to better understand people's responses. The calculated sound levels outside individual homes ranged from less than 30 dB(A) at about half a mile from a turbine to slightly more than 40 dB(A) at about a quarter of a mile from a turbine. Overall, about half of the respondents noticed the wind turbine sounds, but only 8 percent were fairly or very annoyed with the noise [15]. As might be expected, people's response to wind turbine sounds depended on the strength of the noise at their home (Table 1). The surveys were conducted during the summer and most of the annoyance was associated with outdoor activities. About 45 percent of those bothered by turbine noise outdoors were also bothered when indoors and overall, 6 percent reported that turbine noise disturbed their sleep [13].

	29-31 dB(A)	34-36 dB(A)	39-41dB(A)
Do not notice sounds	80%	46%	18%
Notice, but not annoyed	14%	35%	44%
Slightly annoyed	4%	12%	20%
Fairly or very annoyed	2%	7%	18%
Number of respondents	*294*	*318*	*79*

Table 1. Reaction to wind turbine noise outdoors in relation to noise levels outside the home. Percentages are based on Pedersen and Waye 2008 [15].

- *The group of people that reported annoyance with turbine sounds were also concerned about the visual impact of wind turbines.*

The same surveys can be used to further explore people's varying reactions to wind turbine sounds. For example, certain sound qualities, such as swishing, whistling or pulsating were associated with a higher level of annoyance [15]. A negative opinion about the appearance of wind turbines was associated with more annoyance with the noise, suggesting that the visual impact of turbines could influence how noise is perceived [13]. When comparing different regions with similar wind turbine noises, researchers found that a higher percentage of people were bothered by the noise in areas that were rural, had hilly terrain, or had less background noise [14].

The National Research Council, in its analysis of impacts of wind energy development, concluded: "Noise produced by wind turbines generally is not a major concern for humans beyond a half-mile or so because various measures to reduce noise have been implemented in the design of modern turbines" [2, p. 159]. However, perception of wind turbine noise is an area of active research and substantial gaps in knowledge still exist.

Infrasound

- *The noticeable swoosh-swoosh of turbines is almost entirely in the audible range, but turbines also produce some steady, deep, low frequency sounds.*

As communities consider wind development proposals, residents may wonder if wind turbines could produce deep sound vibrations that are potentially harmful to humans. The dominant sounds from wind turbines, the fluctuating swoosh-swoosh, are mostly within the audible range of 500 to 1,000 Hz. The rotors of wind turbines also produce some steady, deep, low frequency sounds (between 1 - 100Hz), particularly under turbulent wind conditions [16,17]. Sound waves below about 20Hz are called infrasound and are audible only at very high sound pressure levels. For example, the deep rumble of thunder includes some infrasound that may be "felt" when thunder is very loud. Older wind turbines that had downwind rotors created noticeable amounts of infrasound, but the levels produced by modern, upwind-style wind turbines are below the hearing threshold for most people [18].

- *People have varying degrees of sensitivity to the sound vibrations from wind turbines.*

The human ear is much less sensitive to sound with very low or very high frequencies. For most people, a very low pitch sound of 20Hz must have a pressure level – or loudness – of 70 decibels (dB) to be audible, and a 10Hz sound must be as loud as 100 dB to be detected [6]. People exposed to very high levels of infrasound (above 115 dB) can experience fatigue, apathy, abdominal symptoms, or hypertension [19]. However, levels of infrasound near modern commercial wind farms are far below this level and are generally not perceptible to people (measured at about 50 -70 dB within 300 feet of a modern turbine) [18]. Most reviews of medical research find that there are no adverse effects – physiological or psychological – of infrasound at these levels [17, 19].

- *Most scientific reviews conclude that infrasound at the levels produced by modern wind turbines does not pose any direct human health risk, but infrasound may make turbine sounds more disturbing.*

Sensitivity to the sound vibrations from wind turbines is variable among people and the potential effects of long-term exposure to low levels of low frequency sound are not fully understood [2]. A recent report by Nina Pierpont, *Wind Turbine Syndrome*, describes the health problems experienced by people living near modern utility wind turbines [20]. Pierpont argues that the low frequency vibrations from turbines are causing migraines, anxiety, vertigo, nausea and increased sensitivity to stimuli among sensitive individuals. Although the report has attracted some attention, it is based on the experiences of 10 families who volunteered to be part of the study because they lived near a wind farm and were experiencing new health problems. This type of case study approach represents a very early stage of medical research – further studies should examine all the people living near multiple wind farms and compare them with similar individuals not exposed to turbine sounds.

Currently, there is little research that supports Pierpont's hypothesis about Wind Turbine Syndrome. Critics of Pierpont's work question whether there is any plausible way for low levels of low frequency sound to impact humans, based on what we know about sound and the human body. They suggest that the symptoms observed result when sensitive individuals are highly annoyed by wind turbine noise and begin to exhibit a stress response [21]. Other reports and studies reviewed for this issue brief conclude that there is no evidence that infrasound from modern wind turbines poses any direct human health risk below 90 dB – which is less than that produced by modern turbines, even within 100 feet of the tower – but infrasound may exacerbate annoyance with turbine noise.

Low frequency sound, like all other sound, diminishes as it travels away from its source, so siting turbines away from homes is a reliable way to minimize any potential risk [18]. However, it's important to keep in mind a couple of points. In flat terrain, low frequency sound can travel more efficiently (with less decay) than high frequency sound. Most environmental sound measurements and noise ordinances are based on the A-weighted decibels (dB(A)) scale, which under-weights low frequency sounds in order to mimic the human perception of sound. Therefore, noise limits based on dB(A) levels do not fully regulate infrasound. The dB(C) scale is an alternative method of measuring sound that gives more weight to the lower frequencies. Regulators may also choose to use the dB(A) scale, but additionally specify maximum sound levels in the low frequency ranges. In West Michigan, Allegan Township's wind ordinance is unique because it specifically regulates low frequency noise.

Noise ordinances in West Michigan

- *Many West Michigan townships have wind energy ordinances which regulate the magnitude of sounds (decibels). However, no ordinances address the character of the sound, which is more difficult to assess.*

Many West Michigan townships have wind energy ordinances which regulate the magnitude of sounds (decibels). However, no ordinances address the character of the sound, which is more difficult to assess. The Ottawa County model wind energy ordinance, for example, suggests that wind turbine noise "shall not exceed, at any time, the lowest ambient sound level that is present between the hours of 9:00 p.m. and 9:00 a.m. at any property line of a residential or agricultural use parcel or from the property line of parks, schools, hospitals, and churches" [4, p.9]. For non-residential or non-agricultural use parcels, the acceptable sound level is the lowest ambient noise level plus 5 dB(A). Michigan's Department of Energy, Labor and Economic Growth also issued a sample zoning ordinance for wind energy systems. The suggested noise limit at the nearest property line is 55 dB(A). When the ambient sound is greater than 55 dB(A), the suggested limit is ambient dB(A) plus 5 dB(A) [22].

- *The Ottawa County model wind energy ordinance suggests a minimum setback of 1,000 feet from an occupied residence.*

  At this distance in the Swedish studies, turbine noise was noticeable but not annoying to about half the residents and fairly or very annoying to 20 percent.

The Ottawa County model wind energy ordinance also suggests a minimum setback of 1,000 feet from an occupied residence. This is roughly the same distance as the loudest sound measurement in the Swedish study [15] at 40 dB(A) and corresponds to about 45 dB(A) in the simple propagation model for a 2.5 MW turbine (Figure 3). In the Swedish studies discussed above, turbine sounds of 40 dB(A) were noticeable but not annoying to about half the residents and at least slightly annoying to about 40 percent (Table 1). Forty dB(A) is the top of the range reported for ordinary nighttime sounds in rural areas and is the recommended limit for nighttime noise in Europe [2, 7, 10]. In order to keep noise below 40 dB(A), municipalities may need to use a more conservative setback distance than 1000 feet, based on the noise propagation model presented in Figure 3. Advances in turbine technology may also enable noise levels to be reduced.

Thirty-six townships in the four-county West Michigan study area have noise ordinances related to utility-scale wind turbines (Figure 5). The most common ordinance sets a maximum sound level at 55 dB(A) as measured at the property line on which the turbine is sited, consistent with the state zoning guidelines. Maximum specified sound levels ranged from 65 dB(A) to 45 dB(A). Most townships made accommodations for conditions where the ambient (background) sound level was greater than the prescribed maximum. In these situations, the maximum sound from turbines was ambient + 5 dB(A).

Some townships included specific times of day or frequencies in their ordinances. Allegan Township, for example, specified a maximum of 35 dB at any octave frequency centered below 250 Hz which covers low-frequency and infrasound. Polkton and Grand Haven townships impose stricter noise controls at night than in the day, which is recommended by the Ottawa County model ordinance [4].

The diversity of noise ordinances may pose challenges for wind energy development. A single wind farm may span multiple townships, each with a different noise ordinance. An acceptable, uniform noise standard could help protect the public health while providing consistent regulations for wind farm operators. Adjacent townships could collaborate on harmonizing their ordinances in a "bottom-up" approach to regional standardization.

- *The diversity of noise ordinances may pose challenges for wind energy development.*

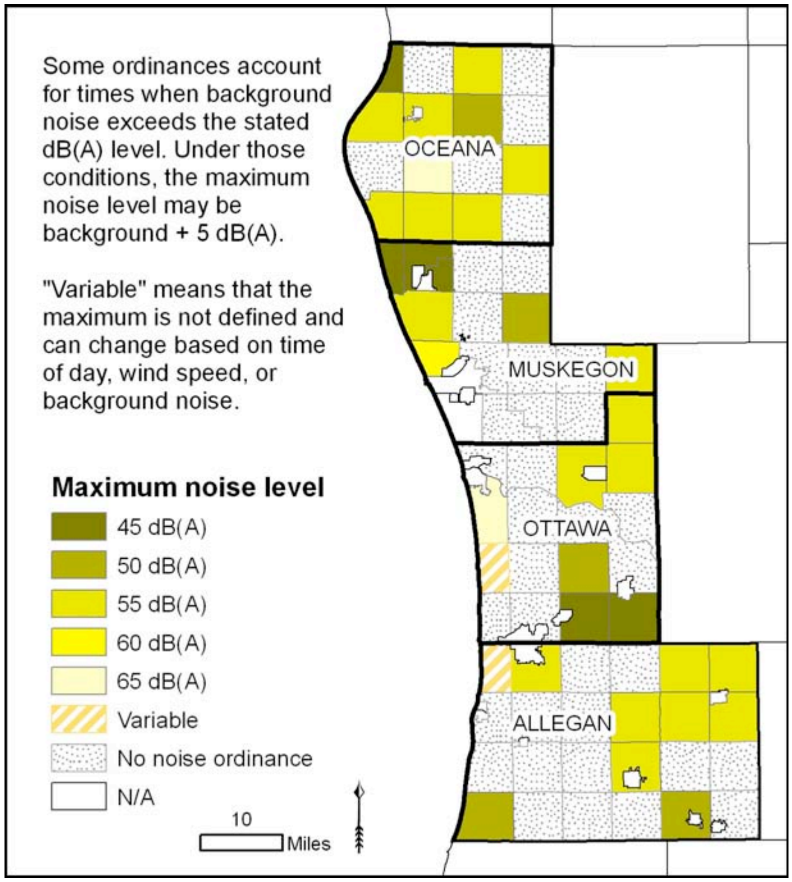

Figure 5. Noise regulations in township wind ordinances in the study region of west Michigan.

Air Quality Improvements

- *Michigan generates about 60% of its electricity from coal, which generates air pollutants that are harmful to human health.*

In order to fully evaluate the impact of wind power on human health we must consider potential air quality improvements. Currently, Michigan generates about 60% of its electricity from coal.[2] If wind energy development reduces Michigan's reliance on coal it could offer significant benefits for human health.

Burning fossil fuels, especially coal, for electricity production generates air pollutants such as nitrogen dioxide, carbon dioxide, ozone, and mercury that are harmful to humans and the environment. Dozens of studies have shown that exposure to such pollutants substantially increases a person's risk of death and serious illness [24]. Medical researchers reported in the scientific journal, *The Lancet*, that emissions from coal-burning power plants cause about 24 deaths, 225 cases of serious illness, and 13,228 cases of minor illness per terawatt-hour (TWh)

[2] In 2008, Michigan produced about 115 TWh of electricity, with 70 TWh of this generated from coal-fired plants [23]

- *Studies suggest that if 10 percent of west Michigan's electricity production was replaced with non-polluting sources like wind, 29 premature deaths, 270 cases of serious illness, and more than 15,000 cases of minor illness could be avoided each year.*

- *West Michigan has four coal-fired facilities with a combined capacity of more than 2000 MW. In Huron County, 78 wind turbines have a capacity of 122 MW.*

of electricity production.[3] Emissions from burning natural gas, a much cleaner fossil fuel, cause fewer than 3 deaths, 30 cases of serious illness, and 703 cases of minor illness per terawatt-hour of electricity production [25].

Electricity production from wind emits no pollutants. The process of manufacturing wind turbine components – the "upstream" environmental impacts – produces small amounts of pollution compared to those associated with building and supplying coal and natural gas power plants [26].

A shift to renewable energy sources, such as wind, could lead to substantial improvements in overall air quality and public health. As an illustration, assume that Michigan's 10 percent renewable energy target (11.5 TWh of 2008 production) will be met mostly with wind energy, and that this capacity displaces coal. Using the health estimates from *The Lancet*, air quality improvements could result in about 275 fewer premature deaths, 2,500 fewer cases of serious illness, and more than 150,000 fewer cases of minor illness in Michigan each year. This example illustrates the potential health benefits of switching to lower-pollution fuel sources; however, predicting how wind energy might alter electricity production and emissions is complex and beyond the scope of this integrated assessment. Depending on the time of day, energy demand and wind conditions, wind energy might replace electricity production from natural gas, coal or other power sources.

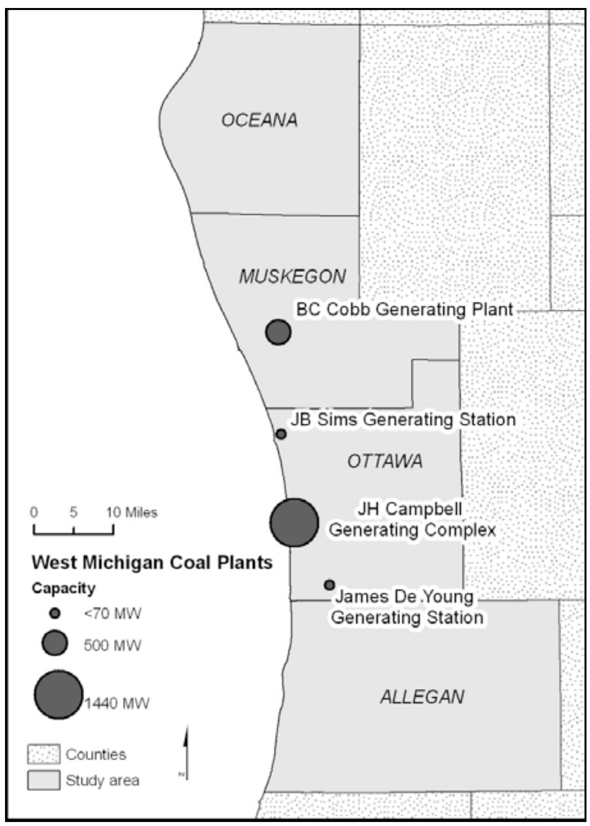

Figure 6: West Michigan's four coal-fired facilities have a combined capacity of more than 2000 MW and produce more than 12 TWh of electricity each year.

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[3] These figures were based on data collected in the United States and Europe. One terawatt-hour (TWh) equals one trillion watt-hours and is enough electricity to power about 125,000 Michigan homes (at 8,000 kWh per household per year). Serious illness includes respiratory and cerebrovascular hospital admissions, congestive heart failure, and chronic bronchitis. Minor illness includes restricted activity days, bronchodilator use cases, cough, and lower-respiratory symptom days in patients with asthma, and chronic cough episodes [3].

The West Michigan study area has four coal-fired power plants in Holland, Port Sheldon, Grand Haven and Muskegon (Figure 6). In 2007, the West Michigan coal generators produced just over 12 TWh of electricity, the most recent year for which detailed, local data was available [27]. If 10 percent of this local electricity production (1.2 TWh) was replaced with non-polluting sources like wind, 29 premature deaths, 270 cases of serious illness, and more than 15,000 cases of minor illness could be avoided each year, based on the *Lancet* figures.

- *Electricity has enabled many advances in human well being, but all forms of electricity generation have some impact.*

West Michigan meets United States Environmental Protection Agency (U.S. EPA) air quality standards for most pollutants, but the region does face some challenges. The Michigan Department of Natural Resources and Environment issued five poor air quality alerts for the Grand Rapids area (which includes part of the study area) in the summer of 2008, tying Detroit for the most alerts of any region in Michigan. Pollution from coal-based electricity production spreads across a broad region, crossing state and national boundaries. The prevailing winds carry some pollution to the region from the west, while dispersing some locally generated pollution to the east. For example Holland's relatively high concentration of ground-level ozone was influenced by pollutant transport across Lake Michigan or along the shoreline [28]. It is difficult to say specifically how wind energy development in West Michigan will improve local air quality, but the regional health benefits could be substantial.

Conclusions

Electricity has enabled many advances in human well being, but all forms of electricity generation have some impact. Pollution from coal-fired power plants, the dominant form of energy production in Michigan, has been linked to premature deaths, and a variety of minor and serious illnesses. Substituting non-polluting sources, like wind, at the 10 percent target would improve air quality and public health in Michigan. However, communities considering wind energy development are likely to face questions about the noise and shadow flicker that wind turbines might produce.

- *In Huron County, wind turbine shadow flicker has not been a concern, turbine noise is noticeable but disturbs relatively few people, and some are concerned about the poorly understood effects of low frequency sound.*

In some northern locations, wind turbines produce a flickering shadow on nearby residences during certain times of the day and year. In West Michigan, wind turbine flicker is unlikely to affect a home for more than a few minutes each day.

The sound of wind turbines is comparable to other sounds in a suburban environment and occurs at levels less than air, road and rail traffic. Some residents living close to wind turbines are annoyed by the regular swooshing sounds of the blades, but recent, though limited, research shows that the sounds disturb a small percentage of residents living between a quarter and a half mile from a turbine. Neither the magnitude nor the frequency of the sounds produced by wind turbines have been directly associated with any adverse health effects, but annoyance can lead to indirect effects. The WHO recommends limiting sound levels outside of homes to 40 dB to protect the quality of sleep and public health, particularly for vulnerable populations. For many utility turbine models, this would require increasing the minimum setback from homes beyond 1000 feet.

In Huron County, Michigan, where 78 large wind turbines have been installed, mostly on farmland, officials recently increased the minimum setback from a home from 1000 feet to 1320 feet. Interviews and comments at public meetings indicate that turbine shadow flicker has not been a concern, turbine noise is noticeable but annoying to relatively few residents, and some are worried about the poorly understood effects of low frequency sound. Roughly a quarter of residents expressed opposition to further wind energy development for a variety of reasons (T. Groth – MSU graduate researcher, personal communication, June 2010).

- *Potential visual and noise impacts from wind turbines can be predicted in advance of construction and minimized through comprehensive zoning ordinances.*

Potential visual and noise impacts from wind turbines can be predicted in advance of construction and minimized through comprehensive zoning ordinances. The Ottawa County model wind energy ordinance specifies that:

- All turbines be located a minimum of 1,000 feet from an occupied residence.
- Shadow flicker on an occupied building shall not exceed 30 hours per year.
- Noise from a turbine at the property boundary of any nearby homes, farms, parks, schools, hospitals or churches shall not exceed, at any time, the lowest ambient sound level that is present between the hours of 9:00 p.m. and 9:00 a.m.

Currently, of the 73 townships in the four-county study area in West Michigan:

- 41 have some type of wind energy ordinance
- 21 townships have an ordinance that specifically address wind turbine flicker.
- 36 townships have a noise ordinance for wind turbines. The maximum allowable noise levels range from 45 db(A) to 65 dB(A).

- *Currently 41 of the 73 townships in the West Michigan study area have wind energy ordinances.*

Public opinion polls in Michigan show that 95% of residents believe that the development of renewable energy is somewhat or very important for the state's economic recovery [29]. However, communities considering wind power projects are likely to have concerns. Comprehensive ordinances, a thorough review and citing process, and science-based information can help communities prepare for wind development proposals.

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Figure 7a. Coal fired power plant in Grand Haven, MI. *(E. Nordman)*

Figure 7b. Wind farm in New York with 83 turbines, each with a 260 foot tower and a capacity of 1.65 MW. *(US Dept of Energy – NREL)*

Literature Cited

[1] Nordman, E. 2009. Regional response to a statewide renewable energy standard: Status and trends of wind energy development in West Michigan. Available at: www.gvsu.edu/wind.

[2] Committee on Environmental Impacts of Wind Energy Projects, National Research Council. 2007. *Environmental Impacts of Wind-Energy Projects*. Washington, D.C.: The National Academies Press. 376 p.

[3] Harding, G., P. Harding, and A. Wilkins. 2008. Wind turbines, flicker, and photosensitive epilepsy: Characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them. Epilepsia 49(6):1095-1098.

[4] Ottawa County Planning Department. 2008. Ottawa County model wind energy ordinance. Available at: http://www.co.ottawa.mi.us/CoGov/Depts/Planning/pdf/Wind_Energy_Ordinance.pdf.

[5] Howe, B., B. Gastmeier, and N. McCabe. 2007. Wind turbines and sound: Review and best practice guidelines. Report submitted to Canadian Wind Energy Association. Available at: http://www.canwea.ca/images/uploads/File/CanWEA_Wind_Turbine_Sound_Study_-_Final.pdf.

[6] Rogers, A., J. Manwell, and S. Wright. 2006. Wind turbine acoustic noise. A white paper prepared by the Renewable Energy Research Laboratory, University of Massachusetts at Amherst. Available at:http://www.ceere.org/rerl/publications/whitepapers/Wind_Turbine_Acoustic_Noise_Rev2006.pdf.

[7] Cowran, J. P. 1994. *Handbook of Environmental Acoustics*. New York: John Wiley & Sons. 296p.

[8] American Speech-Language-Hearing Association. 2010. Noise and hearing loss. Web site. Available at: http://www.asha.org/public/hearing/disorders/noise.htm.

[9] Hume, K. 2010. Sleep disturbance due to noise: Current issues and future research. Noise and Health 12(47):70-75.

[10] World Health Organization Regional Office for Europe. 2009. *Night Noise Guidelines for Europe*. 184 p. Available at: http://www.euro.who.int/__data/assets/pdf_file/0017/43316/E92845.pdf.

[11] Krohn, S. and S. Damborg. 1999. On public attitudes towards wind power. Renewable Energy 16:954-960.

[12] Miedema, H.M.E. and C.G.M. Oudshoorn. 2001. Annoyance from transportation noise: Relationships with exposure metrics DNL and DENL and their confidence intervals. Environmental Health Perspectives 109(4):409-416.

[13]Pedersen, E. and K.P. Waye. 2004. Perception and annoyance due to wind turbine noise – a dose-response relationship. Journal of the Acoustical Society of America 116(6):3460-3470.

[14] Pedersen E and PerssonWaye K. 2007. Response to wind turbine noise in different living environments. Occupational and Environmental Medicine 64: 480–486.

[15] Pedersen, E. and K.P. Waye. 2008. Wind turbines – low level noises interfering with restoration. Environmental Research Letters 3:1-5.

[16] Wagner, S., Bareiss, R., and Guidati, G., 1996. *Wind Turbine Noise.* Heidelberg, Germany: Springer Verlag.. 204 p.

[17] Bastach, M. J. van Dam, B. Sondergaard, and A. Rogers. 2006. Wind turbine noise – an overview. Canadian Acoustics 34(2):7-15.

[18] Jakobsen, J.2005. Infrasound emission from wind turbines. Journal of Low Frequency Noise Vibration and Active Control. 24: 145-155. Available at: http://windfarmrealities.org/wfr-docs/jakobsen-low-freq-noise.pdf

[19] Leventhall, G. 2006. Infrasound from wind turbines – fact, fiction, or deception. Canadian Acoustics 34(2):29-36.

[20] Pierpont, N. *Wind Turbine Syndrome: A report on a natural experiment*. Malone, NY: K-Selected Books. 293 p.

[21] Colby, D.W., R. Dobie, G. Leventhall, D. Lipscomb, R. J. McCunnery, M.T. Seilo, and B. Sondergaard. 2009. *Wind Turbine Sounds and Health Effects: An Expert Panel Review.* Prepared for AWEA and CWEA. 84 p. Available at: http://www.awea.org/newsroom/releases/AWEA_CanWEA_SoundWhitePaper_12-11-09.pdf

[22] Michigan Department of Energy Labor and Economic Growth. 2008. Sample zoning for wind energy systems. Accessed 2 July 2010 from: http://www.michigan.gov/documents/dleg/WindEnergySampleZoning_236105_7.pdf.

[23] Energy Information Administration. 2010. Michigan Electricity Profile, 2008 edition. Web site. Accessed 7 June 2010 from: www.eia.doe.gov/cneaf/electricity/st_profiles/michigan.html.

[24] Pope, C.A. and D.W. Dockery. 2006. Health effects of fine particulate air pollution: Lines that connect. Journal of the Air and Waste Management Association 56:709-742.

[25] Markandya, A. and P. Wilkinson. 2007. Electricity generation and health. Lancet 370:979-990.

[26] Committee on Health, Environmental, and Other External Costs and Benefits of Energy Production and Consumption. 2010. *Hidden costs of energy: Unpriced consequences of energy production and use*. National Academies Press. 466 p.

[27] US Environmental Protection Agency. The Emissions and Generation Resource Integrated Database 2007. Accessed 10 June 2010 from: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

[28] Michigan Department of Environmental Quality. 2008. 2008 Air Quality Report. Available at http://www.michigan.gov/deqair.

[29] Institute for Public Policy and Social Research. 2009. State of the State Survey-51. Michigan State University. East Lansing, MI. Available at: www.ippsr.msu.edu/SOSS

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