REPORT SUMMARY January 2017

A Summary of

Massachusetts Study on Wind Turbine Acoustics

A report by RSG, in cooperation with Epsilon Associates, Inc. and Northeast Wind, 2016

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The *Massachusetts Study on Wind Turbine Acoustics*[2] is a research report initiated by the Massachusetts Clean Energy Center and the Massachusetts Department of Environmental Protection. The study was undertaken to provide information on wind turbine acoustics that could be used to develop testing and modeling procedures to improve wind turbine siting. This final report builds on interim reports that were produced in 2013 and 2014.

To prepare the report, five active wind turbine sites in New England were monitored over a one-year period. To distinguish between background and wind turbine sounds, measurements were taken when turbines were shut down and when they were operating. Sounds were sampled at 330, 660, and 990 meters downwind, crosswind, and upwind of the turbines. Researchers collected predominantly A-weighted sound, which represents the frequency range that most humans typically hear, but some G-weighted measurements, which emphasize the higher infrasound frequencies, were also collected.

The report was written by acoustical engineers and is highly technical in nature. It serves as a guide for those who predict and measure wind turbine sound as well as a rigorous basis for discussing wind turbine noise regulation, modeling, and standards. By providing a plethora of data, it will be beneficial to those who are studying the effect of wind turbine noise on human health.

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[1] This summary, prepared by the Clean Energy States Alliance (CESA), was not reviewed by the report's authors.
[2] RSG et al, *Massachusetts Study on Wind Turbine Acoustics* (Boston: Massachusetts Clean Energy Center and Massachusetts Department of Environmental Protection, February 2016).
http://files.masscec.com/research/wind/MassCECWindTurbinesAcousticsStudy.pdf

Key Findings from the Report

- "Swishing" or "thumping" sounds (amplitude modulation) synchronized with the turning of wind turbine blades can be measured by sound level meters that respond to sound in much the same way as the human ear. Most amplitude-modulated sounds occur in the mid-frequency range of 250 Hz to 2 kHz, which is within the hearing range of the human ear.
- Sound modeling can be used to predict sound levels from proposed wind turbine installations with reasonable accuracy.
- Wind shear (the speed of wind as a function of height above the ground) and turbulence affect sound levels predominantly at lower wind speeds. Vertical wind speed, turbulence, wind direction, and veer have a small effect on sound measurements.
- Wind speed, the number of nearby turbines, and the distance from turbines are the primary determinants of which sounds from wind turbines can be heard by humans.
- A graphical time-series representation of wind turbine sound (by 1/3 octave band level) with the wind turbine on, then off, then on again is generally consistent from turbine to turbine. However, within this "sound spectrum" there may be unique sound signatures caused by mechanical components, which identify individual wind turbines.
- Tones are often the subject of noise regulations since they tend to be annoying compared to "broadband" sounds, which occur over a wide section of the audible range. In considering tones, this study used the American National Standards Institute's ANSI S12.9 Part 4, which describes measurement procedures for assessing and predicting long-term responses to tonality, regardless of its source. It also used by the Massachusetts Department of Environmental Policy which includes a pure-tone standard.
- The study collected approximately 145 million sound level data records. This information will help researchers model sound propagation in a way that would be beneficial during the permitting stage of a wind project. Modeling has limitations but it can estimate the likelihood of exceeding regulatory standards.

Discussion

Amplitude Modulation

Spinning wind turbine blades can cause amplitude modulation, which is a variation in audible sound. As amplitude modulation depth[3] increases, it can be more likely to annoy humans. The study determined that amplitude modulation depended primarily on wind speed and the distance from the turbine. Wind turbulence and wind shear have a smaller, but still statistically significant, effect on amplitude modulation depth.

[3] Amplitude modulation depth is the difference between the maximum and minimum sound level in one cycle of sustained variation.

The study tested three of the five turbine locations (two flat, one mountainous) using a statistical technique that distinguished between background sound and the sound caused by the rotation of the wind turbine blades. Measurements were made near the turbine (approximately 330 meters) to help isolate turbine noise from background noise. The study concluded that predicting amplitude modulation at residential distances beyond 990 meters from turbines is unreliable and requires more study.

Sound Propagation Modeling

Modeling is important because the ability to predict sound levels can determine whether or not a wind turbine will comply with regulatory standards. Although a model cannot guarantee that sound standards will not be exceeded, it can shed light on the probability of compliance.

The study's researchers used two standards to model the sound emitted from wind turbines, ISO 9613, which is the current international standard for modeling, and Harmonoise, a European model. Unlike ISO-9613, Harmonoise has the ability to account for wind speeds and directions, and atmospheric stability. The sound levels predicted by both models were compared to sound monitored during the same time period.

Distance, the number of turbines, and wind speed have the most influence on turbine sound levels. Lesser factors can also influence sound attenuation. Examples of these factors are wind direction, temperature profiles, wind turbulence, ground characteristics (such as porosity and vegetation), and bodies of water over which sound passes. ISO-9613 and Harmonoise predictions varied in their responses to certain conditions, such as ground hardness and flat versus mountainous sites.

Infrasound

Infrasound is sound below 20 Hz, which is the lower limit of human hearing. Although there is considerable interest in infrasound and very low-frequency sounds, they are not commonly regulated in the United States. This study did not examine the health effects associated with wind turbine sound. While infrasounds from wind turbines are typically measured between 60 -70 dB(G), they are consistently below the human auditory threshold of 95 dB(G). People are regularly exposed to infrasound from natural and engineered sources at levels that exceed those produced by wind turbines and there is currently no scientific evidence to indicate infrasound from wind turbines directly impacts human health.[4]

The results of this study confirmed that infrasound is produced by wind turbines and that topography does not have a significant effect on infrasound. Instead, wind speed correlates directly with infrasound. Exterior infrasound does not diminish significantly within lightweight (e.g., wood frame) homes. Turbine manufacturers provide little information about infrasound. Neither ISO-9613 nor Harmonoise model it.

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[4] Berger RG, Ashtiani P, Ollson CA, Whitfield Aslund M, McCallum LC, Leventhall G, Knopper LD, *Health-based audible noise guidelines account for infrasound and low-frequency noise produced by wind turbines,* https://www.ncbi.nlm.nih.gov/pubmed/25759808 (last visited 11/01/2016).

Sound Monitoring

The study examined a variety of sound levels and metrics. Audible wind turbine sounds range from about 50 Hz to 8 kHz. "A-weighted sound level" covers the full audio range from 20 Hz to 20 kHz. At lower levels, it mimics the response of the human ear. Accordingly, environmental noise regulation frequently references this level.

Metrics reflect changes occurring in A-weighted sound levels. Some metrics are preferable to others because they better represent perceived sound levels. For instance, "equivalent continuous average sound levels" (Leq) weighs higher sound levels over time most accurately. It is used in most environmental sound regulations for wind turbines. L90, which describes the noise level exceeded for 90 percent of the measurement period is preferred for measuring the crest of amplitude modulation. L90 is also preferred for differentiating the noise of an operating turbine from background noise.

Meteorological Data

The study examined the effect of atmospheric factors on sound. Rain, relative humidity, temperature, wind speed, and wind direction were measured. The relationship between wind shear and wind turbulence was one factor of interest. Typically, wind speed increases with height. Turbulence refers to the change in wind speed with time. A wind gust is an example of turbulence.

Wind shear and turbulence have more impact on sound levels at low wind speeds than at high wind speeds. Because a wind turbine generates its maximum sound output at higher wind speeds, modeling is not as accurate at lower speeds.

Tonality

Tones are sounds that are discernible from "broadband" sounds. Some tones, such as the buzz of a fly, are annoying. Some environmental noise regulations apply specifically to tonal sounds within a specified narrow frequency range.

Tonal sounds were detected from wind turbines about three percent of the time. The study recognized that the spectrum of background noise can erroneously cause sounds to be considered tonal. Ignoring background sounds resolved this, but failed to account for the human ear's variable sensitivity to tones at different frequencies. Results can be improved with more sophisticated instrumentation, but at a cost in both money and expertise. Simpler methods are not as accurate, but are more practical in the field.

About the Report and Its Authors

The ***Massachusetts Study on Wind Turbine Acoustics*** report, released in February of 2016, was prepared for the Massachusetts Clean Energy Center and the Massachusetts Department of Environmental Protection by Resource Systems Group, Inc., in cooperation with Epsilon Associates, Inc. and Northeast Wind. Resource Systems Group designs, implements, and applies data-driven models with analytics to predict why systems perform as they do. The group was founded by Dartmouth College professors in 1986. Epsilon Associates is an environmental engineering and consulting company specializing in environmental approvals for projects for public and private sector clients. Northeast Wind (Vermont Environmental Research Associates) provides a variety of wind project management and assessment resources to private and public clients.


MASSACHUSETTS STUDY ON WIND TURBINE ACOUSTICS

RSG the science of insight

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MASSACHUSETTS CLEAN ENERGY CENTER

MassDEP Commonwealth of Massachusetts Department of Environmental Protection

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This paper is part of a series by the Northeast Wind Resource Center, a project managed by Clean Energy Group and CESA, to provide accessible, concise summaries of technical studies related to land-based wind in the Northeast.

If you have suggestions for studies that should be summarized, please send your suggestions to LBWStaff@northeastwindcenter.org.