Project: A healthy society - towards the optimal management of wind turbine noise

D4.2 Guidelines for acquisition and assignment of reliable model input data and parameters for a given wind farm

Projekt: **Healthy society - towards optimal management of wind turbines' noise**

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Executive summary

There are several models available for prediction of noise propagation outdoors. Most models have been developed for the prediction of sound propagation near the ground, i.e., both the source and the receiver are located close to the ground. Models for aircraft noise are based on a very different principle and uses so-called NPD tables (Noise Power Distance). These data tables have often been established as part of the aircraft certification.

Work is currently being done to modify existing models to accommodate also sources located high about the ground, such as wind turbines.

Three different noise prediction models have been assessed as possible candidate methods for wind turbine noise prediction. Current Polish noise regulations require the calculation of several noise indices in addition to the common Lden. It has been concluded that only the NORD 2000 model can accommodate those needs.

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Report

Wind turbine noise prediction methods

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SUMMARY
Three candidate models for noise propagation predictions for wind turbine noise have been described and evaluated. The NORD 2000 model is the only one that will produce noise indices that are required according to current Polish noise regulations.

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1 Introduction

Wind turbine installations may have a large environmental impact on the surroundings. National and local authorities usually require that this impact is quantified and documented before a building permit is granted. Planners of such installations therefore have to rely on different noise prediction methods in order to produce a reliable environmental impact assessment. Various indicators may be requested depending on relevant noise regulations.

2 Basic requirements

Several prediction programs for wind turbine noise are commercially available. An important part of these programs is the propagation module that calculates how the noise propagates through the atmosphere from the source to the receiver under various meteorological and ground surface conditions. For some advanced programs the propagation module may be interchangeable depending on local conditions and requirements specified by the authorities for instance as part of the noise regulations.

The most common noise index that is required in an environmental impact assessment is the weighted yearly average equivalent noise level, L_{den}, as specified in the European Directive 2002/49 (EU Parliament and the Council of the European Union, 2002). This quantity is assumed to correlate with the annoyance a group of residents living at that location (a community) will experience. However, other national or local noise regulations may require additional information. In order to check compliance with Polish noise regulations, the prediction model must also be able to calculate the eight-hour equivalent level for an "average day", $L_{pA,8h}$, and the highest one-hour equivalent level, $L_{pA,1h}$, during the night for the "average 24-hour period". Other requirements may be the maximum noise level that may be experienced in a specific location, and the maximum day, evening and night levels that may occur.

3 Noise propagation models

3.1 ISO 9613

ISO 9613 Acoustics — Attenuation of sound during propagation outdoors (ISO, 1993) (ISO, 1996) is a general-purpose methodology for calculating outdoor sound propagation. It is used in many forms and situations all over the world. One example is the official practice in Great Britain, France and Austria, who point to ISO 9613-2 for calculation of shooting noise. Another is the German aircraft noise model AzB which refers to it for calculation of ground attenuation. The method was developed in the 1990s for use with ground-bound noise sources. It is not clear how well the method handles propagation of sound high above the ground. The method is referred to by several specialized ISO standards, like (ISO, 2018) (ISO, 2015).

The core algorithms for sound propagation have been derived from older empirical-oriented methodologies. Having been surpassed by more physical-oriented methods for ground attenuation and screening, ISO 9613 can no longer claim to be state-of-the-art. But its simplicity gives it a clear advantage over newer methods when it comes to implementation and calculation costs.

The following parameters are taken into account:

Atmospheric absorption is handled by the input parameters temperature and humidity.
Ground attenuation. The ground properties are specified as hard or porous ground or a mix between the two. So, any degree of porosity can be defined.

The method can predict the average L_{den}, but since wind speed and wind direction is not specified ISO 9613 cannot be used to predict the noise for a specific situation under given meteorological conditions. The method assumes moderate down-wind conditions in all directions.

ISO 9613-2 CALCULATIONS

For practical calculations the first step will be to establish the propagation path between the source and the receiver. In its simplest form the terrain between the two is considered flat and the location of the source is defined as the height above this flat surface. Similarly, the receiver height is referred to this flat area. The standard has information on how to calculate the mean height, and additional information on how to handle screening by terrain or other barriers.

Then the propagation path is divided into three sections: the source region equal to 30 times the source height, the receiver region equal to 30 times the receiver height, and the middle region equal to the left-over part of the total distance.

For a wind turbine the source section may be typically 2500 m to 3000 m. If the total distance from the base of the source to the receiver is less than the source region, the standard specifies how the distance should be divided into sections.

The ground absorption is defined by a ground factor, G, as either soft/porous (G=1) or hard (G=0) or any number between zero and one depending on the fraction of the region that is porous. For G=1 the attenuation reaches its maximum value, and hence the sound level in the receiver location is at a minimum. For noise predictions at an early stage in the planning process it is recommended to use values of G less than 1 for conservative reasons even if the ground seems to be "soft" all the way between the source and receiver.

Atmospheric absorption is defined by a combination of temperature and humidity. An absorption factor can be found from a table with temperature and humidity as input parameters. This absorption factor is frequency dependent and should be specified for each octave band from 63 Hz to 8000 Hz. The standard has a table for the general attenuation coefficient and formulas for calculating the octave band values.

Similarly, the source strength, defined as the sound power level should also be specified for the same octave bands.

The sound level in each octave band is calculated based on the source level and the attenuation in that particular band. Finally, the contributions from all eight bands are added and possibly A-weighted to give the sound level in the receiver position.

The standard also specifies a simplified method for direct calculation of A-weighted levels.

3.2 Cnossos-EU

The EU Directive 215/996 (EU Commission, 2015) contains a description of a general method for calculation of outdoor noise propagation for use with road, railway, and industrial noise sources. The method is often referred to as Cnossos-EU, after the EU funded research project where it was specified (Kephalopoulos, Paviotti, & Anfosso-Lédée, 2012).

The propagation model in Cnossos-EU is based on a French method NMPB 2008 which originates back in the early 1990ies. After getting status as preferred EU method, Cnossos-EU has gotten much attention internationally. Several improvements have been published. Further, it is being evaluated for ISO quality assurance, and it is being evaluated for official status as the national noise mapping method in several countries. Like ISO 9613, Cnossos-EU is intended for ground-bound noise sources (typically road and rail traffic). The consequence of applying it to elevated source positions (high-rise wind turbines) is not explored.

Cnossos-EU calculates L_{den} on the basis of a set of input parameters:

- Acoustic output from the source
- Directivity of the source
- Average yearly operation
- Type of noise source
- Source and receiver location
- Ground conditions
- Topography
- Atmospheric conditions

The acoustic output from a wind turbine depends on the wind speed. The noise level increases with the wind speed up to about 10-12 m/s and then typically levels out. The noise calculation is carried out for a specific wind speed, usually defined by regulatory authorities. The source level at this nominal speed must be known for each relevant octave band. The frequency spectrum is represented by eight octave bands from 63 Hz to 8kHz. This implies that the noise level is calculated for operations at nominal wind speed, regardless of the actual speed at which the turbine is operating.

The noise emitted from the wind turbine has a certain fixed directivity pattern but seen from a nearby location the directivity pattern depends on the wind direction. The Cnossos-EU model does not consider wind speed as calculation parameter but include the effect of meteorological variation through probability distribution between homogeneous (no wind) and favorable (down-wind) atmospheric condition. This distribution can be changed for prevailing winds if certain wind directions are considered to occur more often than others.

The hours of operation are described statistically: so and so many days of operations per year, or preferably so and so many hours of operation during the day, evening and night per year.

The Cnossos-EU method has been developed for various types of noise sources. A wind turbine is considered a point source. The location of the source and receiver and their relative location with respect to the ground plane is an important parameter. Similarly, the acoustic properties of the ground plane (absorbing, reflecting) must be known.

The Cnossos-EU model is based on standard atmospheric conditions (temperature and humidity) and two types of atmospheric conditions – "favorable" or "homogeneous". Homogeneous implies no wind, which also means no noise production.

The Cnossos-EU model calculates the L_{den}, the yearly average time-weighted equivalent level. If the hours of operation are known in detail (hours per day, evening and night), it is possible to extract the equivalent level for each period, day, evening and night, of an average 24-hour period. It is, however, not evident that the highest 8-hour day period is associated with the average 24-hour period that is used for the Lden calculations. Likewise, the highest one-hour night period may occur during different conditions than what is used as the L_{den} reference period.

Detailed predictions of quantities other than L_{den} cannot readily be performed.

Cnossos-EU CALCULATIONS

Cnossos-EU defines the sound source either as a collection of single point sources or as incoherent line sources. The process of establishing the propagation paths between the source(s) and receiver(s) is similar to that defined by ISO 9613-2. Atmospheric absorption for each octave band can be found on the basis of temperature and humidity similar to the definitions in ISO 9613-2.

The ground plane connecting the source and receiver is defined by sampling the distance between the line of sight and the real terrain in multiple discrete points and performing a least square error regression to establish the mean plane across this terrain. The height for the source and the height for the receiver are defined relative to the mean plane.

For a point source the sound level is found by subtracting the attenuation along the propagation path from the directional sound power level. The attenuation includes the attenuation due to geometrical divergence, atmospheric absorption, ground effects and diffraction. Cnossos accounts for diffraction effects from obstacles encountered along the propagation path. Should the path traverse sufficiently far above the diffraction edge of an obstacle, the model negates the diffraction's impact, effectively setting its contribution to zero.

Cnossos utilizes two different propagation modes, allowing for the incorporation of meteorological variations: the homogeneous propagation condition, characterized by a linear path directly connecting the source and receiver, and the favorable propagation condition, where the path curves, with the curvature's radius being influenced by the linear path's length. This framework permits a flexible weighting between these two propagation scenarios.

Practically speaking, homogeneous conditions are characterized by no wind and stable temperature and favorable conditions are characterized by downwind. Special weather conditions with for instance strong headwind and/or temperature inversion cannot be handled by the Cnossos propagation models.

Ground effect attenuation is defined by the porosity of the ground surface as for the ISO 9613 method. The method defines a G-factor between zero and one where "1" denotes a very soft ground and "0" represents a very hard and dense surface. For situations where the distance from the base of the wind turbine to the receiver is less than about 30 times the height of the source (hub of the wind turbine) the ground properties near the source and receiver becomes negligible.

3.3 NORD 2000 method

The NORD 2000 method calculates the equivalent noise level for a certain period based on a set of input parameters. In addition to the ones used by Cnossos-EU the method can handle detailed meteorological input data for specific weather conditions. In order to simplify the input procedure, the model comprises a set of predefined weather classes. So, instead of defining each single meteorological parameter, one can choose a "weather class" that is somewhat similar to the actual local condition. The method operates with a large selection of weather classes covering all normal variation ranges of wind, temperature, temperature gradients, air stability, and turbulence. For practical purposes only a small number (9 classes) are being used.

Real weather statistics representing long-term meteorology can be used to model the "average situation". This is done by calculating the noise for all weather classes and then averaging the results after weighting them by probability of occurrence.

NORD 2000 calculates the equivalent noise level for a stable situation described by a set of input parameters. The model can be used to calculate the noise under any chosen conditions as long as these can be described by relevant meteorological and operational parameters. Thus NORD 2000 can be used to calculate relevant acoustical properties like L_{den}, $L_{A,8h\ day}$, $L_{A,1hmax\ night}$, L_{AFmax}, etc.

In most cases the sound propagation conditions may be characterized by four different types: unfavorable, neutral, favorable, and very favorable. It should be noted that these characterizations refer to the sound propagation. So, under unfavorable conditions the sound does not propagate very far meaning that the noise level at some distance from the turbine is low. This will create a favorable noise situation for the people that are living nearby. Similarly, under very favorable weather conditions, the sound propagates across a long distance, creating a very unfavorable noise situation for the neighbors.

Nord 2000 CALCULATIONS

The Nord 2000 method calculates the noise under specific meteorological conditions. For long-term indices, such as Lden, the calculations must be repeated for different conditions and then the results are combined on the basis of weather statistics.

The first step in a Nord 2000 calculation is to determine the weather class. In order to simplify the description of meteorological conditions for sound propagation calculations a concept of weather classes has been introduced. These weather classes can be defined using standard meteorological parameters like wind speed, wind direction, cloud conditions and time of the day. The two latter parameters define meteorological stability that describes, among other things, the temperature gradient.

The weather classes can be found from a special table that lists combinations of the different meteorological parameters. A total of 25 weather classes have been defined, but 16 of these are not very common. That leaves 9 classes that are sufficient to characterize most meteorological situations. In Nord2000 all 9 weather classes can be handled. In order to get an initial impression of the noise situation for a planned wind park, it may be sufficient to use only four weather classes: unfavorable, neutral, favorable, and very favorable. Calculations using very favorable weather conditions will show the highest noise levels that can be experienced. (Note that very favorable refers to the sound propagation itself, meaning very little absorption and hence the highest exposure levels).

Under unfavorable conditions the sound waves will bend upwards and the sound level at some distance from the source will be low. Under neutral conditions the sound propagates in straight lines, and under favorable conditions the sound waves will be bend towards the ground. This will give higher sound levels at some distance, and the sound may seem to propagate beyond obstacles. The sound level may be high even if the direct line of sight between the source and the receiver is blocked.

The ground surface is important for the attenuation of the propagating wave. The porosity of the ground is described by the flow resistance. The Nord2000 calculation program divides the flow resistance in eight classes, A—H. Class A "very soft" (moss, snow) has a flow resistance σ = 12,5 kPa/m2 , and class H "very hard" (asphalt, concrete, water) has σ = 200 000 kPa/m2 . At a distance of 100 meters the sound from an 80 meters high wind turbine will differ only 2 dB between class A and class H ground surface (class H gives higher level). At 300 meters the difference is 2.2 dB. The calculation has been done for flat terrain and free line of sight between the turbine and the observer.

This calculation can be considered an extreme situation. It is very rare to have a surface class H "very hard", similar to G=0 in ISO 9613, all the way between the turbine and the receiver (except propagation across water). The difference between summer conditions and winter conditions when the ground is covered with snow, will therefore normally be smaller than shown above. Class D, σ = 200 kPa/m2 , is a good approximation for the ground in typical rural areas (hard grass covered ground). At 300 meters the difference between class A and class D is only 1.5 dB for an 80 m high turbine.

The wind speed is not critical for downwind situations. Downwind means the wind is blowing from the turbine and towards the observer. The A-weighted downwind sound level from an 80 m high turbine will be the same at wind speeds 1 m/s up to 16 m/s for distances up to 1000 meters (the source level is assumed to be constant). The reason for this is that downwind the sound will propagate high above the ground and the terrain will have minimal effect.

Upwind, that is wind blowing from the receiver towards the turbine, the situation is different. At moderate distances, 300-500 meters, the effect is small. At 500 meters the sound level will decrease only 0.8 dB if the wind speed increases from 1 m/s to 16 m/s. but at 1000 meters the reduction will increase to 16.4 dB. The reason for this is that the sound waves will propagate a long distance close to the ground and will be effectively absorbed. These calculations are valid for flat terrain.

At locations perpendicular to the wind direction, the effective wind speed can be considered zero, and hence the wind speed has no effect.

4 Comparative considerations

ISO 9613 is relatively simple to use whereas the two other methods, Cnossos-EU and NORD 2000, require a certain acoustical expertise and cannot be successfully used by people without such background. However, the NORD 2000 method is much more advanced than the Cnossos-EU method and thus requires a higher level of competence.

The NORD 2000 method can calculate relevant acoustical quantities like L_{den}, $L_{A,8h\ day}$, $L_{A,1hmax\ night}$, etc. used by Polish regulatory authorities, as long as these periods can be described by meteorological parameters. The Cnossos-EU method initially calculates L_{den} only, but other quantities may be extracted using statistical operational data. The method cannot be used to calculate the noise for any chosen combination of meteorology and operational parameters.

The NORD 2000 method is implemented in the software package Soundplan. This is a relatively expensive package and cannot be assumed to be available for the general acoustical consultant. The Cnossos-EU method, on the other hand, will presumably be implemented in most noise prediction programs.
Neither of the two methods have been fully developed for wind turbine noise, and there are still prediction issues that remain unsolved. For certain given meteorological conditions, the two methods can yield quite different results. The difference is too large to be classified as being within a normal uncertainty range.

5 Recommendations

We consider the NORD 2000 method superior as this method is, to a large extent, based on physical models rather than pure empirical approaches. However, since calculations with this model requires a high level of acoustical competence (and relatively complicated and expensive software), we will recommend a hybrid solution.

We have given our Polish partners in the HETMAN project free access to the NORD 2000 calculation core. We suggest that they use this to calculate the noise for a large number (tens of thousand) of combinations of wind turbines and operational and meteorological parameters. This information can be stored in a "library". A simple program that will choose the most relevant precalculated "noise map" based on a description of the actual situation is offered to planners, consultants etc. that need to predict the noise from new or existing wind farms. This will allow people without extensive acoustic competence to produce relevant noise maps and will secure a unified way of dealing with wind turbine noise.