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The masking effect of vegetation- and wave noise on wind turbine noise audibility

Lars Sommer Søndergaard[1], Rune Egedal[1], Erik Thysell[1], Franck Bertagnolio[2] and Andreas Fischer[2]
[1] Department of Acoustics, Noise and Vibrations, FORCE Technology, Denmark,
[2] DTU Wind and Energy Systems, Wind Turbine Design Section, Denmark
Corresponding author: lss@forcetechnology.com

Summary

In Denmark and several other countries noise is regulated as absolute levels, hence the audibility of the noise source is not directly handled.
In most countries, including Denmark, wind turbines are often set up in rural areas. Denmark is a flat, windy and in general densely populated country, but the rural areas are less populated and has longer distances between dwellings, and so it is easier to comply with the setback distances and noise demands. Coincidently some of the windiest parts of Denmark are also rural areas.
In the rural areas some of the common sources of noise is vegetation or waves, which masks other environmental noise sources. The effect of masking from vegetation and/or waves has not been studied in much detail in Denmark.
The aim of this project is to gather data from vegetation noise and wave noise and use this to form simple models for both vegetation noise and wave noise. The models are used to estimate the audibility of wind turbines erected in rural areas, considering both temporal effects, spectral effects and effects of wind turbine size, distance and wind shear.
This paper introduces the background and current status of the project, which is based on the Danish noise regulation for wind turbines and a number of investigations/projects.

1. Introduction

Denmark is a windy, densely populated and flat country surrounded by water, where the highest natural points are approximately 170 m above sea level. Figure 1 shows both the population density, the energy production from onshore wind per municipality, onshore and offshore wind turbines operating in 2021 and a wind resource map – all for Denmark. It can be seen that the largest wind resources typically are in the least populated areas of Denmark which also are the areas where most wind turbines are installed. Consequently, some of the areas where wind turbines are installed and have been installed are areas where the background noise level is dominated by not man-made noise sources such as vegetation noise and wave noise + sounds from birds etc. It should be noted that even though these areas are some of the least populated areas in Denmark, dwellings are still spread all over the area. This leads to the fact that distances between dwellings and wind turbines are relatively small.

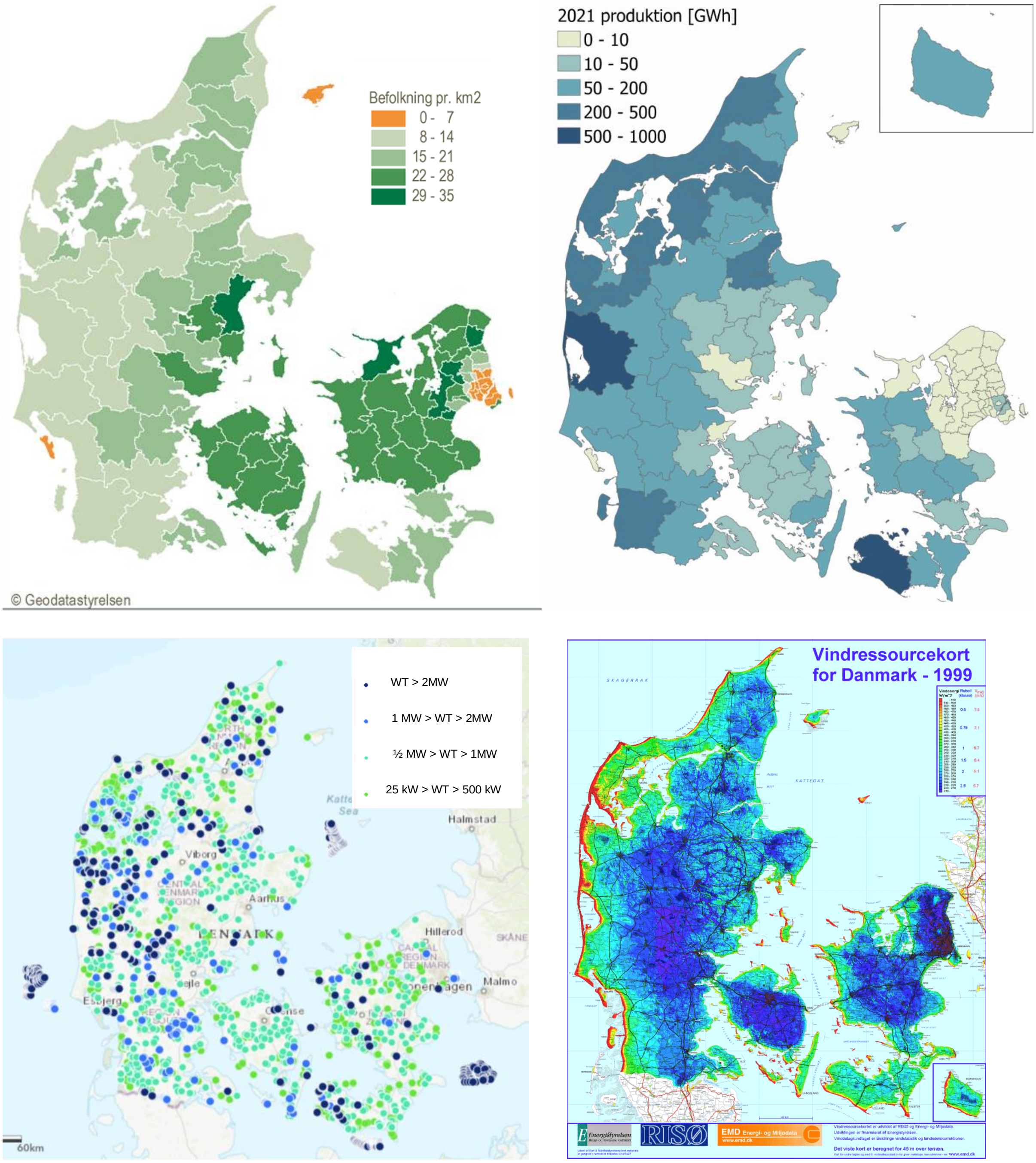

Figure 1: Top left: Population density pr. municipality for rural districts (https://www.dst.dk/da/Statistik/nyheder-analyser-publ/nyt/NytHtml?cid=30696). Top right: Energy production from onshore wind pr. municipality (https://ens.dk/sites/ens.dk/files/Statistik/oversigtskort_over_produktion_pr_kommune_fra_landvind_2021.png). Bottom left: Onshore and offshore wind operating in 2021 (https://www.arcgis.com/home/webmap/viewer.html?webmap=4398142262974c4b9b41ac477d423dcd&extent=7.4005,54.9737,15.514,57.524). Bottom right: Wind resource map for Denmark in 1999 (https://www.emd-international.com/files/windres/images/RES_DK99_25pct.gif).

2. A short introduction to the regulation of noise from wind turbines in Denmark

In Danish, the word “vindmølle” is used both on the modern electrical power producing “wind turbine” and the historical “windmill” even that there now only are a few left of the historical type. Denmark is a windy country with a long history of utilizing the wind. It is one of the first countries in the world to have a specific regulation for noise from wind turbines, the BEK 304 dating 1991 [1]. BEK is a shortening of ‘Bekendtgørelse’ which translates to ‘statutory order’. The following period is characterised as a transition period with much discussion regarding how to handle this “new” noise source. Wind turbine noise can only partially be handled by the noise regulation for environmental noise from industry. Two of the biggest differences are:

- Noise regulation for environmental noise from industry specifies that it should be documented for a wind speed lower than 5 m/s (which only is a bit higher wind speed than the typical cut-in wind speed for many wind turbines at the time)
- The noise changes with wind speed

In the transition period a letter was send out to the county administration on how to handle this in the meantime, dating 1988 [2]. The letter is commonly referred to as ‘The county letter’.

Before the first real regulation, BEK 304, and the county letter many investigations and research projects were performed, leading to overall principles of how the wind turbine noise is handled in Denmark. The regulations were finally based on sound power level measurements, which were used as input to a noise calculation of the noise level at receivers position. This is also the general principle for handling environmental noise in general in Denmark.

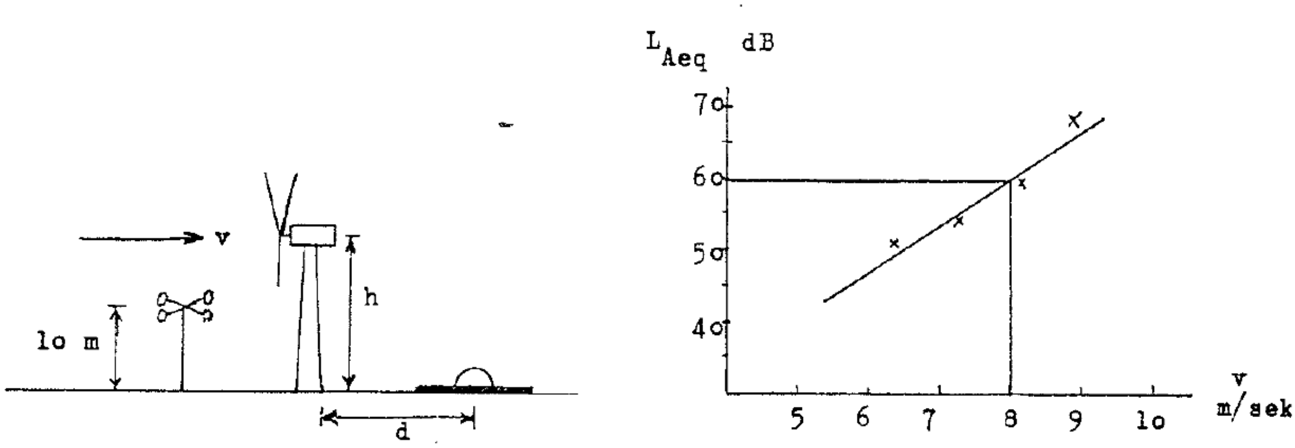

Figure 2: Figure from the county letter [2]*, where the left side shows the principle of the sound power level measurement, and the right side shows the typical result of such measurement.*

At the time the first wind turbine noise regulation were defined, the most typical wind turbine in Denmark was the stall regulated wind turbine. It typically had a noise vs. wind speed pattern as shown in the right side of Figure 2. The noise vs. wind speed relationship can approximately be described as a straight line, where the noise level (L_{Aeq}) at wind speed 8 m/s at 10 m height and the slope was used for noise documentation. The sound power level measurement was a very simplified version of what is now the IEC 61400-11 method [3].

The typical total height of the wind turbines installed at the period when the first noise regulation was defined, was approximately 30-50 m, see Figure 3. Since then, the wind turbines have grown steadily bigger, and now areas for a coming test center are screened to allow for even larger turbines – possibly up to a total height of 450 m. [4]

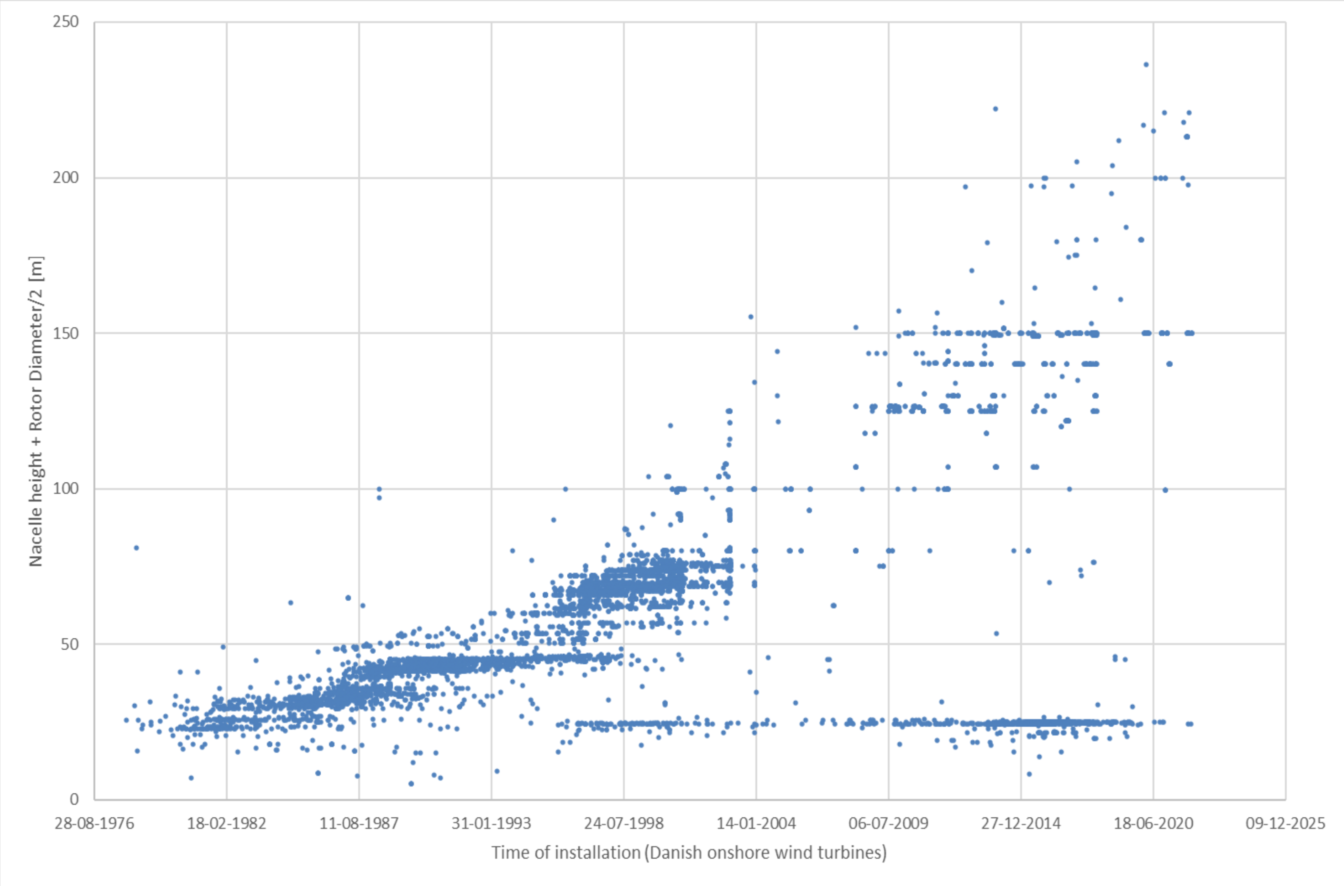

Figure 3: Total height (nacelle + rotor diameter/2) for all land-based wind turbines installed at some point in Denmark. List from https://ens.dk/service/statistik-data-noegletal-og-kort/data-oversigt-over-energisektoren. The list was downloaded on the 13-03-2023. NB: The turbines with a total height larger than 150 m are primarily test turbines primarily placed at the two test centers Høvsøre and Østerild.

The height is of course not the only parameter which has changed over the years. Other relevant changes regarding noise are blade design, drive-train design and naturally wind turbine control. In Denmark, especially in the years up to 2009, there was a large jump in size, but also a change from stall regulated turbines to pitch/RPM controlled turbines. Instead of an approximately linear relationship between noise and wind speed as with the stall regulated wind turbines, typically a linear relationship between noise and wind speed is seen up to the wind speed where rated power is reached – whereas for higher wind speed the noise is approximately constant, see Figure 4.

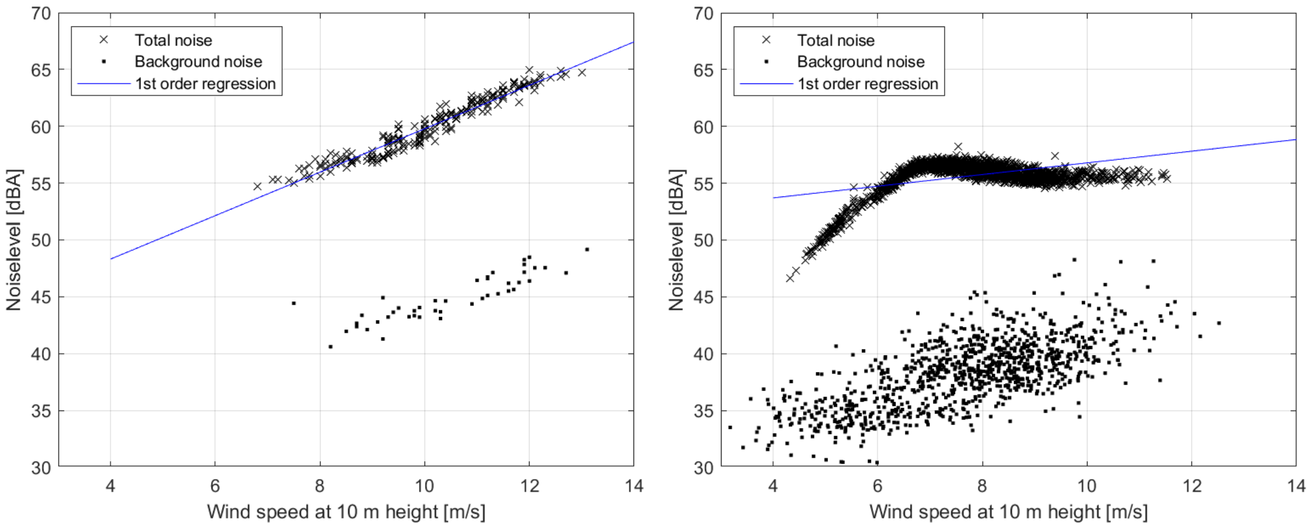

Figure 4: Left: Typical scatterplot (noiselevel versus wind speed) for a stall regulated wind turbine. Right: Typical scatterplot for pitch/RPM controlled wind turbines. [5], [6]

In 2006 a new version of the noise regulation for wind turbines was introduced [7]. Multiple changes were introduced but most importantly in the context of this paper was the change of noise propagation calculation method, the introduction of 6 m/s as a control wind speed and a more detailed sound power level measurement. For the wind turbines installed these years typically the wind speed where the wind turbines reached rated power was between 6 and 8 m/s at 10 m height, and with the noise levels measured at wind speeds of 6 and 8 m/s the noise curve was controlled. Since then, the regulation has been updated several times. In 2012 new noise limits for low frequency noise was introduced [8]. A journal paper [9] was published in 2012 by the Danish EPA describing the Danish noise regulation for wind turbines. In 2019 the noise propagation over water was updated and the tonality method changed [10].

The complexity of the noise regulation has followed the development of the wind turbines. The noise regulation from 1991 had approximately 1800 words. The current noise regulation (from 2019) has approximately 7200 words.

2.1 Current noise regulation

The current regulation for noise from wind turbines in Denmark is from 2019 [10]. In short, it states that the cumulative noise level from all relevant wind turbines may not exceed the following limits:

- At the most noise-exposed point in outdoor living area no more than 15 metres from dwellings in the open countryside:
    (a) **44 dB(A)** at a wind speed of **8 m/s** (10 m height).
    (b) **42 dB(A)** at a wind speed of **6 m/s** (10 m height).
- At the most noise-exposed point in areas with noise-sensitive land use:
    (a) **39 dB(A)** at a wind speed of **8 m/s** (10 m height).
    (b) **37 dB(A)** at a wind speed of **6 m/s** (10 m height).

The total low frequency noise from wind turbines at wind speeds of 6 and 8 m/s (10 m height) may not exceed **20 dB indoors** in neither dwellings in the open countryside nor indoors in areas with noise-sensitive land use. The low frequency noise level is the A-weighted level of the noise in the frequency range defined by the 1/3-octavebands from 10 Hz to 160 Hz, including both.

The noise level at these points is calculated based on sound power level measurements with a prescribed noise propagation method, where there is a method both for noise propagation over land and over water. For the indoor low frequency noise level there are defined sound insulation values both for regular houses and for summer cottages (typically with a lower sound insulation). The regulation also describes how to handle tonality content in the wind turbine noise.

2.2 Setback distance

In Denmark since at least 1999 there has been determined a setback distance as 4 times the total height of the turbine (nacelle height + rotor diameter / 2 for regular wind turbines). The current version [11] describes it as follows (Translation by the author):

- *§ 2. Stk. 2. Permission must not be granted according to the planning act for wind turbines closer to neighboring dwellings than 4 times the total wind turbine height.*

3. Noise from wind turbines and the masking effect of vegetation

Lydteknisk Institut (Now FORCE Technology) performed in 1988 a project for the Ministry of Environment, the Ministry for Energy and Elkraft AmbA (Now Ørsted). The purpose of the project was to examine, to which degree the natural wind noise (vegetation noise) masks the noise from wind turbines. The title of the project report was “Noise from wind turbines and the masking effect of wind noise” [12]. The aim was to investigate to which degree the natural wind noise caused a complete masking of the wind turbine noise, and where it would be fair to relax the noise limits. The project contained a literature study of the theory of masking and its application for wind turbine noise and natural wind noise. In parallel the natural wind noise was measured on different locations. Based on the findings it is generalized that:

- The wind turbine noise is, in a given moment masked by the wind noise, when short time Leq of the turbine noise for all critical bands are at least 4 dB below the sound pressure level of the wind noise.

The generalized wind noise (vegetation noise) is compared to measured wind turbine noise (Nordtank 130 kW, Vestas 75 kW small generator and Vestas V75 kW large generator). It is concluded that the higher the wind speed the better the wind turbine noise is masked, meaning that higher wind speed increases the possibility of the wind turbine noise not being audible. It is also noted that even weak tonal components affect the masking.

Remark that this study is from 1988 and that the measured wind turbines are stall regulated wind turbines, which are characterised by a linear relationship between noise and wind speed, see Figure 4.

4. Wind turbine height and shear

The propagation of sound from different sources like wind turbines is influenced by wind speed and air temperature variations with height above terrain. These variations can be characterized by atmospheric stability. Based on these facts and the findings published in [13], another study for the Danish EPA was conducted “Noise from wind turbines during night”. Its purpose was to investigate to which extent the meteorological conditions influence noise from wind turbines, in the surroundings with special regard to the difference between day and night.

A stable atmosphere is characterised by strong shear (a large velocity gradient with respect to height) and low turbulence levels. It occurs typically during night and in clear weather conditions. In a stable atmosphere, the wind speed observed at hub height of a wind turbine, is higher than the one observed in a neutral atmosphere at same wind speed for 10 m height. In an unstable atmosphere, the mixing of the flow between layers of the atmosphere is more present than in stable conditions. As a consequence, the wind shear is usually weak, and the turbulence levels are high. Stable conditions are typically encountered during night-time and especially in clear weather. The wind speed at hub height of a wind turbine equivalently will be lower than observed in a neutral atmosphere with the same wind speed at 10 m height. Since the noise transmission from the wind turbine depends on the wind speeds at the height of the rotor disc, it will therefore be experienced, that the transmitted noise (sound power level) at a constant wind speed at 10 m height will vary depending on the stability of the atmosphere. The biggest difference between wind speed at hub height and at 10 m height will occur during night. Analysis of meteorological data was performed for data from four chosen synoptic Danish weather stations supplemented with extensive meteorological data from Høvsøre (Danish test site for large wind turbines). Two of the stations are located far from the coastline and the rest are located close to the coastline. All locations are spread geographically in Denmark. On the basis of these data, general statistics about wind conditions has been made, and wind speeds for the heights 10 m and 90 m above terrain are compared.
The difference between wind speed at hub height and at 10 m height is seen to be larger at night than during day as described in literature [13]. Generally, wind speed at 10 m height is lower at night than during day, whereas the wind speeds at hub height generally do not differ significantly. In Figure 5 the cumulative frequency of the wind speed for day and night shows that the difference between night and day is small for wind speeds measured in 90 m height but large for wind speeds measured in 10 m height at Høvsøre.

Based on these measurements, the noise emission from wind turbines is not expected to be higher at night than during the day. But if the sound power level of a tall wind turbine is determined on the basis of the measured wind speed at 10 m height, sound power level measurements performed during the night might overestimate the noise emission from the wind turbine significantly compared to the reference conditions from the Danish regulations.

Seasonal variation is seen only to influence the conditions at 10 m height, whereas the influence at wind speed at hub height will be insignificant.
No indication of influential differences is seen between coast near locations compared to inland locations besides the differences to be explained by higher average wind speed.
Lower wind speed at 10 m height is expected to cause a lower background noise level at the residents close to wind turbines. It is possible that the lower masking from background noise level could lead to higher nuisance under these conditions. [14], [15]

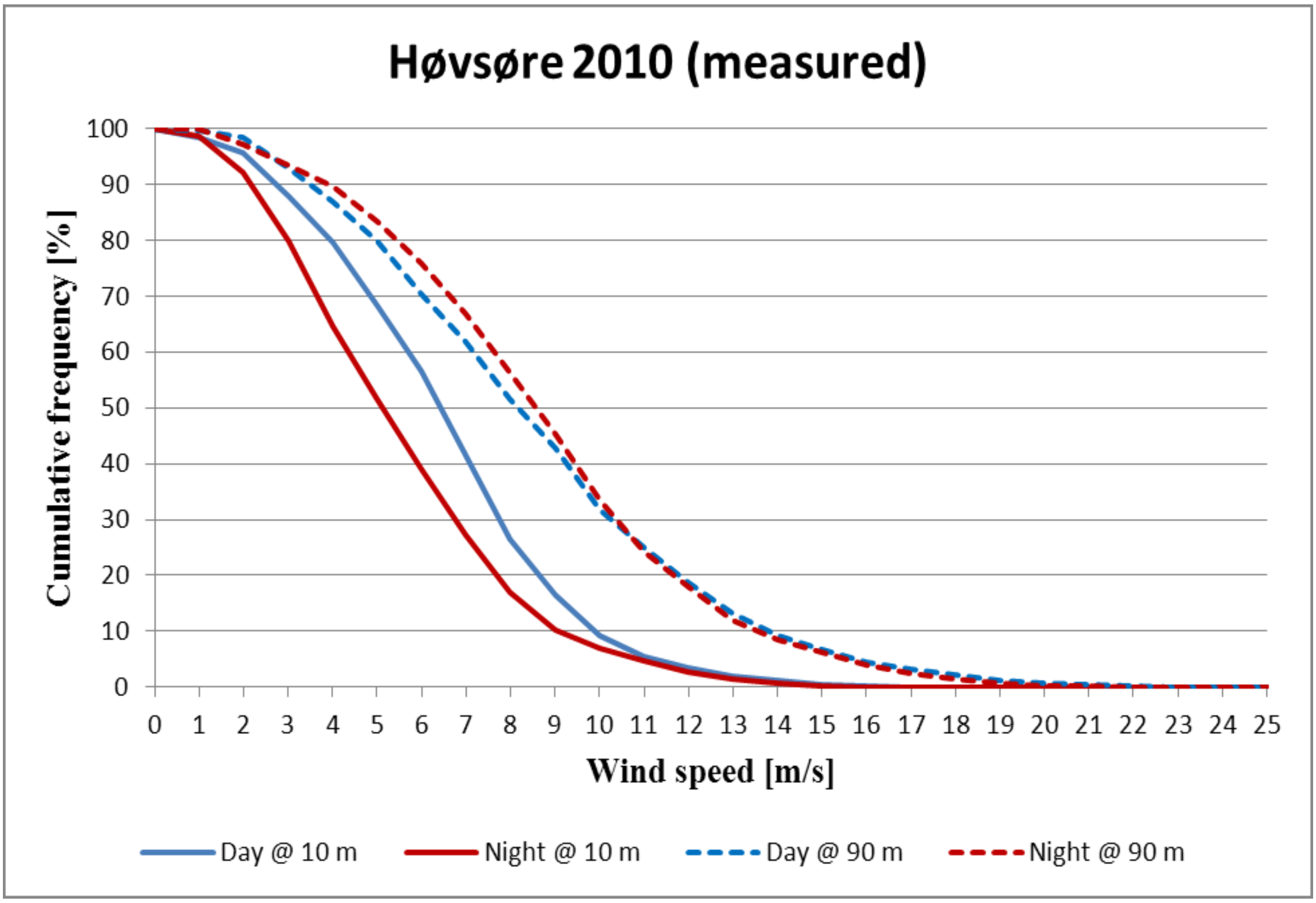

Figure 5: Cumulative frequency for day and night for wind speeds measured in 10 and 90 m height at Høvsøre

5. Wind turbine noise measurements at dwellings versus sound power level measurements and calculated noise levels

As mentioned previously noise from wind turbines in Denmark are controlled based on sound power level measurements. The received noise levels are at receiver position are computed with a predefined propagation method. Hence, the parameter that is in principle controlled is the sound power level from the turbines weighted with a sound propagation function.
There has been uncertainty from residents/neighbours whether the sound propagation methods were correct and questions why the noise is not measured where they live.

Consequently, the Danish EPA initiated three projects to investigate this further and compare results from the default procedure with measurements at residents. The results are reported in three Danish reports and summarized in two conference papers [16]–[20]. In general, it is concluded that it is sometimes possible to measure the wind turbine noise at receivers' position, but that in general that background noise is typically of the same magnitude as the wind turbine noise or even higher. When it was possible to measure the wind turbine noise at the receivers position comparable results to the default procedure (L_{WA} measurement + calculation) were found, but it was more difficult and time consuming than the default procedure.

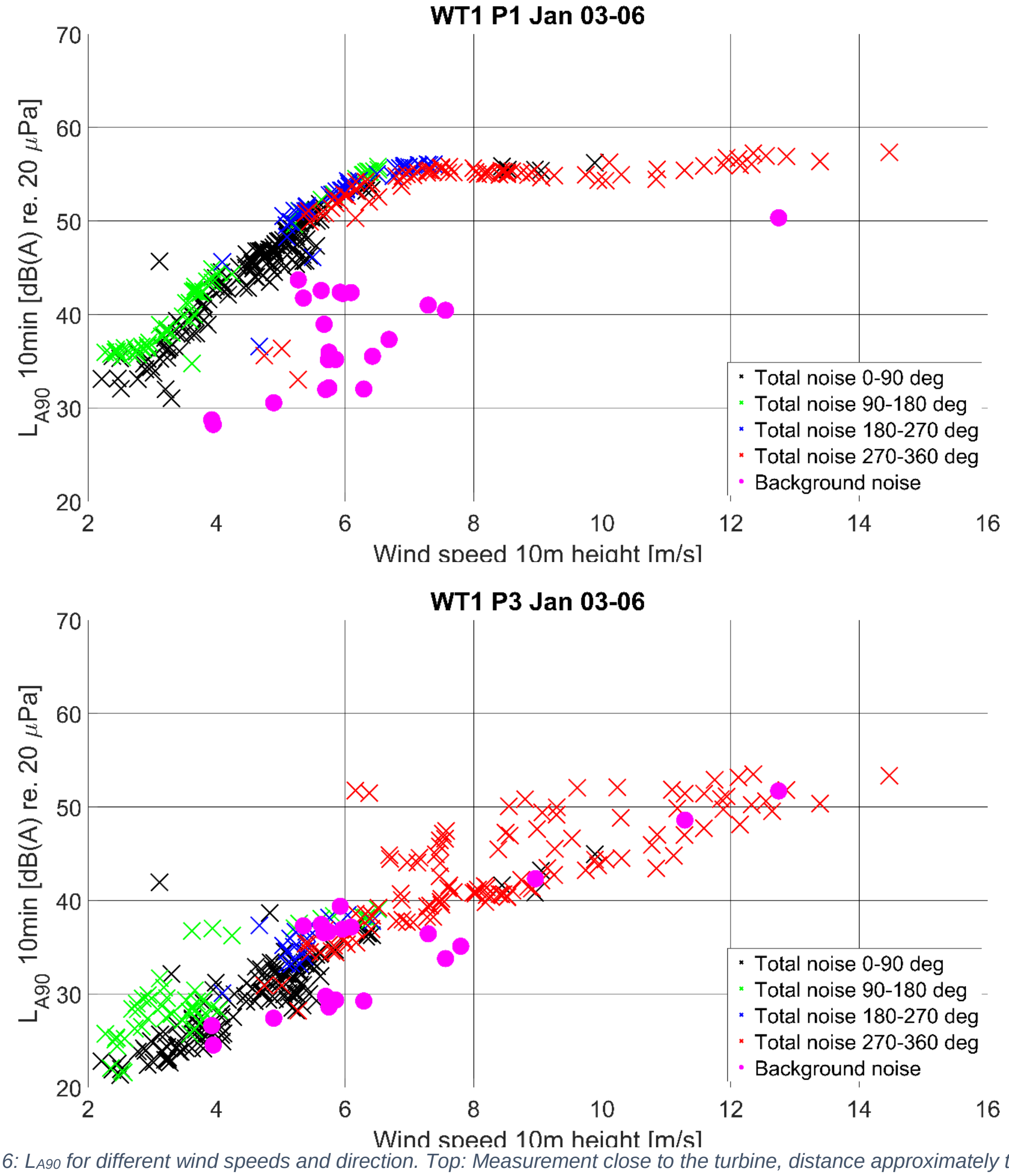

Figure 6: L_{A90} for different wind speeds and direction. Top: Measurement close to the turbine, distance approximately the same as the total height of the turbine. Bottom: Measurement at dwelling, distance approximately 4 times the total height of the turbine.

In Figure 6 a plot from one of the measurements [20] is shown. The top plot shows the results of the measurement close to the wind turbine (approximately a sound power level measurement). There is a clear difference between the background noise and the total noise. For the bottom plot simultaneous data at the nearby dwelling is shown (a distance approximately 4 times the total height of the turbine) where the background noise level is approximately the same as the total noise.

6. Background noise in L_{WA} measurements

When the sound power level of wind turbines is measured the background noise level is also measured. These measurements are performed in a downwind distance from the turbine equal to the total height of the turbine [3], [10]. A Danish study from 2016 [5] compared the sound power level versus wind speed for a large number of wind turbines. In addition, the difference between measured noise levels with the turbines on and off was also shown, Figure 7. Typically, these measurements are performed in daytime for practical reasons. The largest difference in noise level with turbines on and off are in the 6-8 m/s wind speed interval.

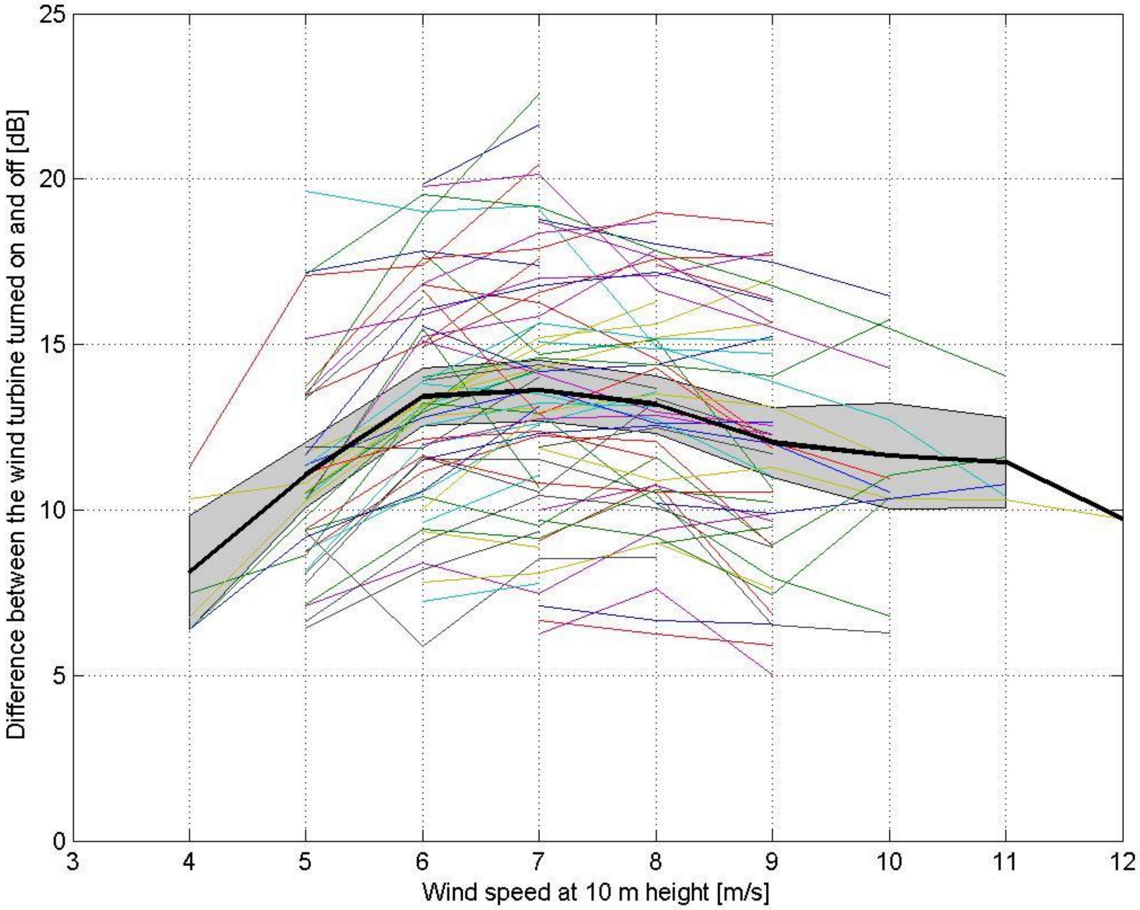

Figure 7: Typical differences between wind turbines on and off versus wind speed in 10 m height for 51 different wind turbines measured over a total of 74 days. The difference for each measurement is shown together with the arithmetic mean + 95 % confidence level.

7. Vegetation noise

Vegetation noise as a function of wind speed is not often documented in Denmark (unless as part of background noise for sound power level measurements for wind turbines). When documented it is typically for short periods (between hours and within a day) where some examples are shown in [21].

As part of the DecoWind project [22] long term monitoring was performed at a relatively quiet site with a single wind turbine. The wind turbine was shut down during several periods of the measurement campaign to determine the background noise. The L_{Aeq} in a frequency range of 50 Hz to 8000 Hz and for 10 seconds periods were computed to characterise the background noise. The L_{Aeq} versus wind speed is shown in Figure 8 for two different microphone positions and filtered according to day and night time. The noise level in general is higher in the day period than in the night period. There is some correlation between wind speed and noise level. However, the scatter of the data is rather large and masks the correlation between wind speed and noise level. This scatter is because some of the measured background noise was caused by human or animal activity at the site. The activity was lower during night than during day. Because of the large amount of data, it is not possible to filter manually for vegetation noise. It is necessary to develop an algorithm that performs this filtering. Filtering might help to reveal the correlation between vegetation noise and wind speed more clearly.

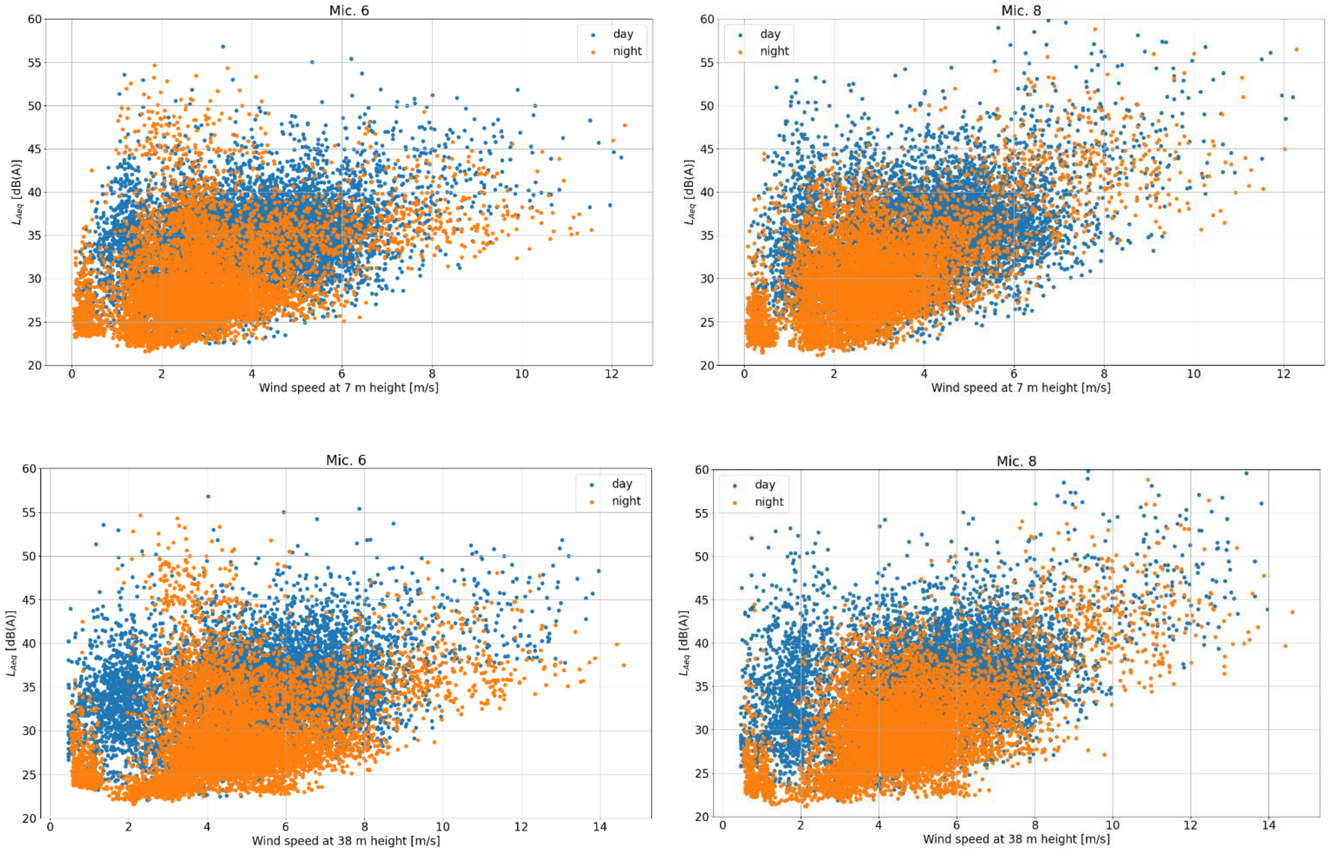

Figure 8: Background noise (primarily vegetation noise) as a function of wind speed measured between March 4th and April 9th of 2020. The data has been filtered for time of day, where day is between 5h to 18h and night between 18h to 5h. The daytime data set contains 7788 samples of background noise, the night time data set contains 7634 samples. The data is plotted both as a function of wind speed determined by a sonic anemometer at 7 m height and a cup anemometer at 38 m height. The instruments were positioned approximately at a distance of 600 meters to microphone 6 and 1000 m to microphone 8.

8. Noise from waves

Most Danish onshore wind turbines are positioned inland, but a few are placed at the beach/harbour. The background noise data obtained from a sound power level measurement on wind turbine located on a beach placed at the North Sea is shown in Figure 9. There seems to be a weak relationship between wind and noise.

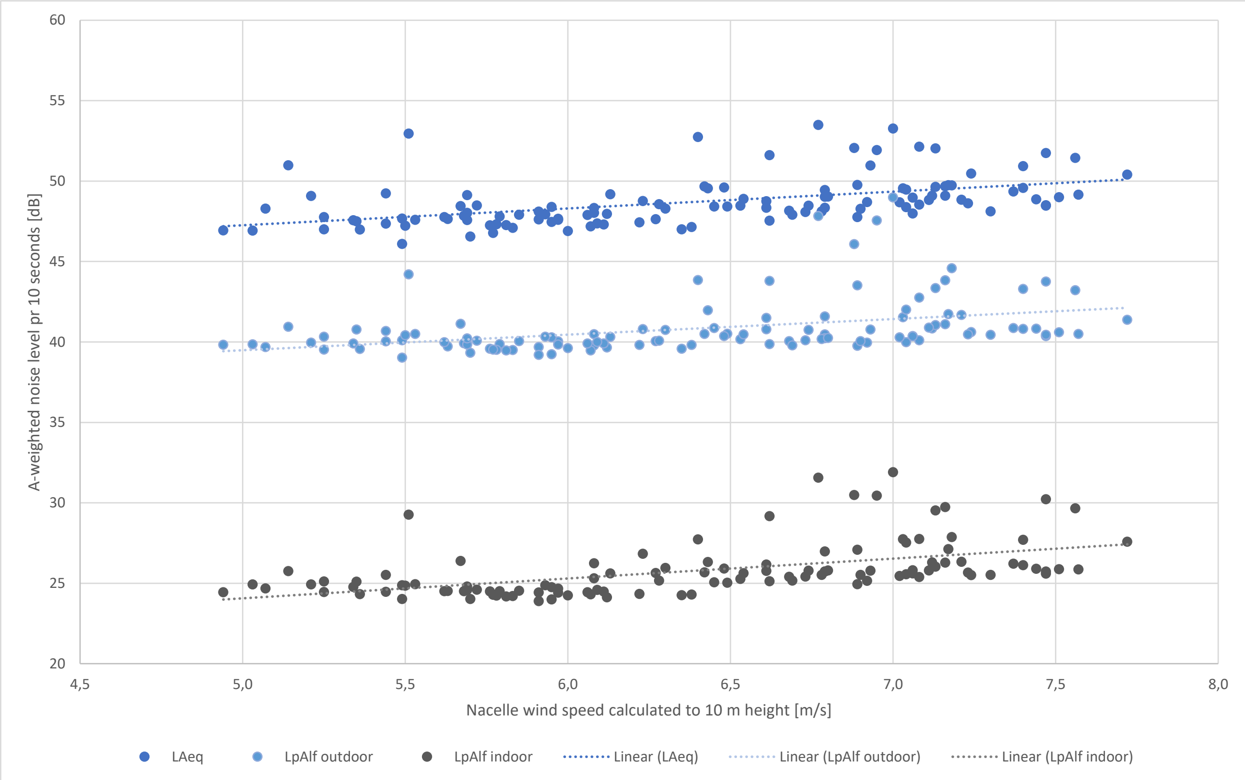

Figure 9: Measurements of background noise over 2 x 10 minutes at a beach around noon at the western part of Denmark performed in relation to sound power level measurements of wind turbines (wind turbines was off during this part of the measurement). The microphone was on a plate on the ground, and there was a small sand dune between the microphone and the water – approximately distance 20-30 m between microphone and water.

Another measurement is part of the DecoWind project [23] where measurements was performed at Dragstrup Vig which is part of Limfjorden. The microphone was positioned just next to the water. The relationship between wind speed and noise level is shown in Figure 10.

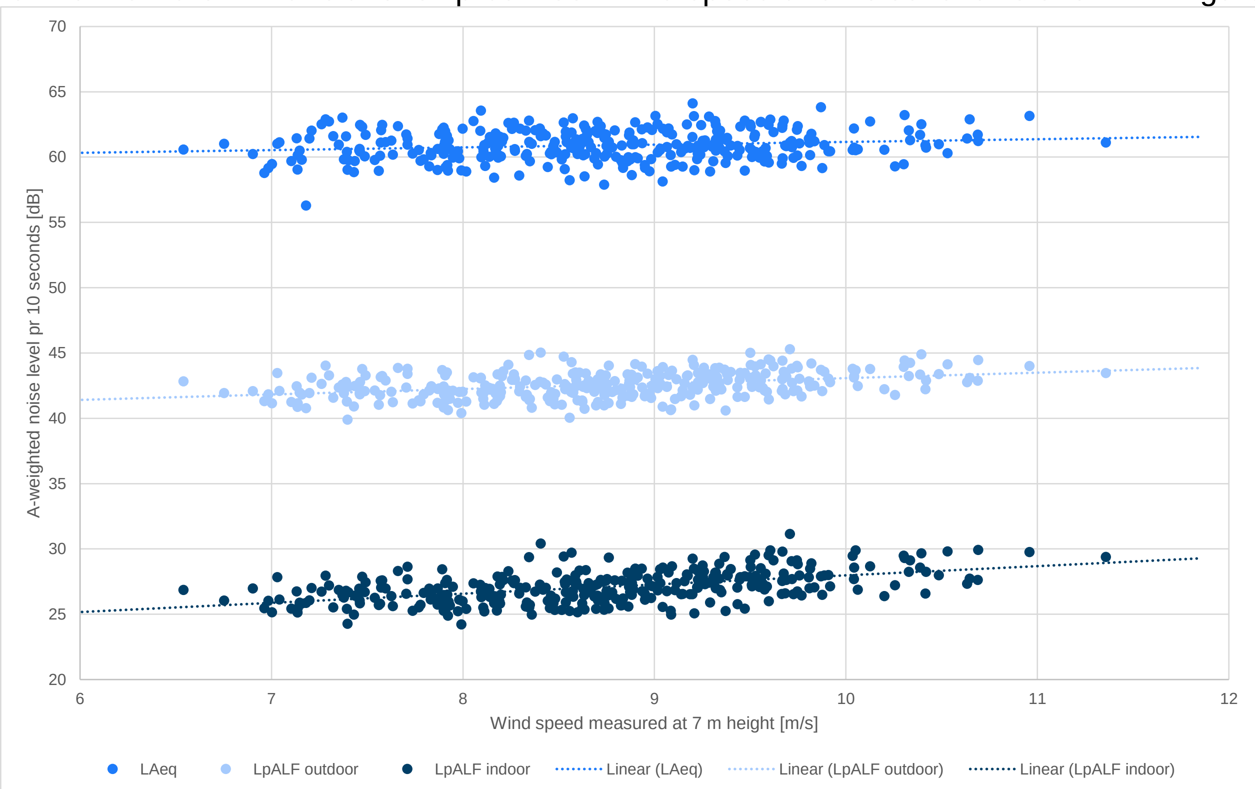

Figure 10: Measurement of background noise for different periods as part of the over water measurements at Dragstrup Vig at the 8 km distance position. Total of approximately 50 minutes during daytime. The microphone was on a tripod with an approximate height of 1.5 m above ground and approximately 3 m from the water.

9. Socio-acoustic study

As part of the DecoWind project [22] a socio-acoustic study was carried out [24]. The annoyance of 68 neighbours to pitch regulated wind turbines over a period of 6 weeks was surveyed by use of an app-based daily questionnaire. Additionally, both the short time noise level and the 24h noise level was modelled. Only neighbours who could hear the turbines were recruited. The wind speed in the period of the study was lower than typical, and as a result only few periods with a maximum level of 44 dB was achieved. The results presented in Figure 11 show that the participants in the study were in general not at all annoyed. It cannot be concluded whether this is also true for higher wind speeds, but at least it can be concluded that wind turbine noise was in general not at all annoying under present conditions during the study. It can also be seen that even estimated noise levels up to 44 dB were found to be not annoying at all – even though few occurrences occurred.

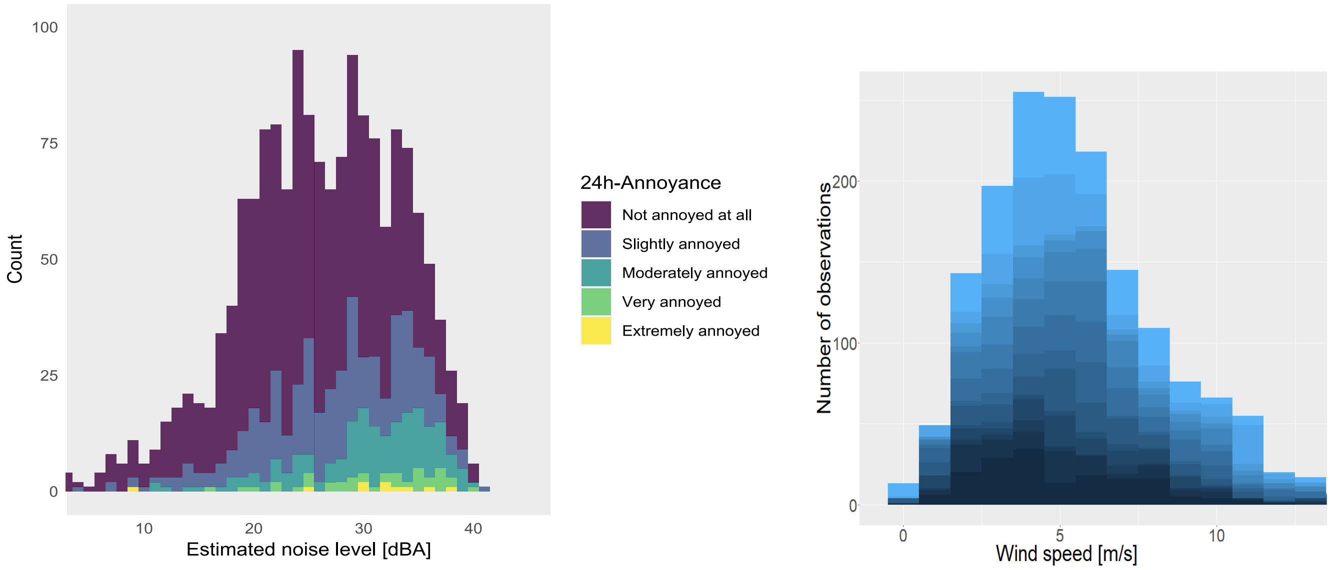

Figure 11: Selected results from the socio-acoustic study in the DecoWind project. Left: Estimated noise level and annoyance. Right: Wind speed

10. Conclusions

To sum the findings from the previous sections, the Danish noise regulations are originally based on assumptions that vegetation noise and background noise in generally to some degree masked the wind turbine noise. An early study of vegetation noise, wind turbines and audibility concluded that the wind turbine noise was masked if the noise level in each critical band was at least 4 dB lower than the masking background noise/vegetation noise. In this document only absolute levels have been shown, and firm conclusion on audibility can therefore not be drawn, but only hinted.

Since then, wind turbines have developed – both in size and in design. One study has investigated differences in wind speed at different height. Based on the findings it can be speculated that there is a risk of the wind turbines being more audible the higher they are.

Other studies have compared wind turbine noise measured at dwellings with calculated noise following the default Danish method for determining the noise level at dwellings, with the general conclusion that often background noise is of the same magnitude as the wind turbine noise.

Measured wave noise shows noise levels higher than the Danish wind turbine noise limits hinting that at least for these locations wind turbines might not be audible. Measured vegetation noise for a single site shows noise levels between 25 – 55 dB with wind speeds of 6-8 m/s hinting that at least some of the time a wind turbine at this position might/will be audible.

A recent socio-acoustic study showed that the participating wind turbine neighbours in general were not at all annoyed by the noise, however the wind speed for the study period was in general lower than the necessary wind speed for the wind turbines to reach rated power.

The possible total height of wind turbines continues to grow, and with the Danish setback distance rule of minimum distance to neighbours of 4 times the total height the possible distance to neighbours continues to grow as well. In Denmark most wind turbines are installed in areas with low population density, and thereby possible sounds which can mask the noise from the turbines are often only natural sounds like vegetation noise and wave noise. Both vegetation noise and wave noise are also wind driven, however with growing height and growing distances there is a risk that correlation between the wind which drives the wind turbines and the wind which excite vegetation and waves grows weaker, and that the masking possibility of vegetation noise and wave noise are diminished.

The purpose of this project is to better describe and quantify the potential masking noise from vegetation and waves, both based on collected data from Denmark, but potentially also with data and knowledge from outside Denmark.

11. Future and on-going work in the project

Focus of the project so far has been on gathering Danish data and knowledge (some of it shown in this paper) and establishing possible collaboration. Further literature will be studied, and by collaboration hopefully data and knowledge from outside Denmark will be gathered as well.

Collaboration with Karl Bolin has been established, who has performed short term measurements of sea wave noise, for the Baltic Sea, and studied the wave noise as a function of wave height [25]. Computation with the empirical model for vegetation noise presented in [26] will be compared to the vegetation noise data gathered in the present study. We further plan to compare our findings with studies of related topics that have been presented in the literature [27]–[30].

In addition to the already gathered Danish data set, measurement systems with microphones close to the shore of a fjord and nearby vegetation have been set up. These systems will have already been collecting data for 3 weeks on the day of the deadline of this paper. It is the intention to measure additional sea noise but at the North Sea, and these data will be compared with the results presented in [25] and [26].

In this paper only the total noise level has been shown, but it is the intention to compare wind turbine noise with the masking noise for critical 1/3 octave bands, and possibly perform listening tests as well.

Acknowledgements
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References

[1] Miljø- og fødevareministeriet, *Bekendtgørelse om støj fra vindmøller nr. 304 af 14/05/1991*. Denmark: Miljø- og Fødevareministeriet, 1991. [Online]. Available: https://www.retsinformation.dk/eli/lta/1991/304

[2] H. Sandbech and P. B. Suhr, *Brev til amtsrådene af 28. april 1988*. 1988.

[3] IEC, "IEC 61400-11 Wind turbines - Part 11: Acoustic noise measurement techniques." 2012.

[4] P. Alexandersen, "Stort behov for et tredje test-center til store vindmøller," *Green Power Denmark*, Aug. 08, 2022. https://greenpowerdenmark.dk/nyheder/stort-behov-tredje-testcenter-til-store-vindmoeller

[5] L. S. Søndergaard and C. Backalarz, "Støj fra store , nyere danske vindmøller som funktion af vindhastigheden," Miljø- og Fødevareministeriet, 2016. Accessed: Apr. 23, 2023. [Online]. Available: https://www2.mst.dk/Udgiv/publikationer/2016/04/978-87-93435-66-7.pdf

[6] L. S. Søndergaard and C. Backalarz, "Noise from wind turbines and health effects - Investigation of wind turbine noise spectra," in *6 th International Conference on Wind Turbine Noise*, Wind Turbine Noise Conference, Glasgow, 2015, 2015.

[7] Miljø- og fødevareministeriet, *Bekendtgørelse om støj fra vindmøller, BEK nr 1518 af 14/12/2006*, vol. 2006, no. 1518. 2016, pp. 1–9.

[8] Miljøministeriet, *Bekendtgørelse om støj fra vindmøller*. 2011.

[9] J. Jakobsen, "Danish Regulation of Low Frequency Noise from Wind Turbines," *Journal of LOW FREQUENCY NOISE, VIBRATION AND ACTIVE CONTROL*, vol. 31, no. 4, pp. 239–246, 2012.

[10] *Bekendtgørelse om støj fra vindmøller*, no. 135. Denmark: Miljø- og Fødevareministeriet, 2019, pp. 1–24.

[11] Erhvervsministeriet, *Bekendtgørelse om planlægning for og tilladelse til opstilling af vindmøller*. 2019.

[12] J. Jakobsen and T. H. Pedersen, "Støj fra vindmøller og vindstøjens maskerende virkning.," Lydteknisk Institut, Apr. 1989.

[13] G. P. Van Den Berg, "Effects of the wind profile at night on wind turbine sound," *J Sound Vib*, vol. 277, no. 4–5, pp. 955–970, Nov. 2004, doi: 10.1016/j.jsv.2003.09.050.

[14] K. D. Madsen and B. Plovsing, "Støj fra vindmøller om natten," 2012. [Online]. Available: https://www2.mst.dk/Udgiv/publikationer/2012/05/978-87-92779-91-5.pdf

[15] L. S. Søndergaard, "Noise from wind turbines under non-standard conditions," in *41st International Congress and Exposition on Noise Control Engineering 2012, INTER-NOISE 2012*, 2012.

[16] B. Søndergaard, J. Heiden, and N. F. Christensen, "Måling af støj hos vindmøllenaboer Mindre vindmøllepark Målinger i dag og nat perioden - Miljøportalen nr. 2048," Nov. 2018.

[17] B. Søndergaard, J. Heiden, and N. F. Christensen, "Måling af støj hos vindmøllenaboer : større vindmøllepark målinger i dagperioden - Miljøprojekt nr. 2096," Miljøstyrelsen, Aug. 2019.

[18] R. Egedal, N. F. Christensen, and B. Søndergaard, "Danish experiences with measuring wind turbine noise at neighbor dwellings," in *8 th International Conference on Wind Turbine Noise Lisbon-12 th to 14 th*, 2019.

[19] C. Søndergaard, Lars Sommer; Egedal, Rune; Hansen, Morten Bording; Pedersen, Torben Holm; Backalarz, "Støjmålinger hos naboer til vindmøller i Nollund," 2017.

[20] R. Egedal, M. B. Hansen, and L. S. Søndergaard, "Wind turbine noise at neighbor dwellings, comparing calculations and measurements," in *INTER-NOISE 2017 - 46th International Congress and Exposition on Noise Control Engineering: Taming Noise and Moving Quiet*, 2017.

[21] L. S. Søndergaard, R. Egedal, and M. B. Hansen, “Variation of wind induced non-turbine related noise due to position, shelter, wind direction and season,” in *7th International Conference on Wind Turbine Noise Rotterdam – 2nd to 5th May 2017*, 2017, pp. 1–14.
[22] F. Bertagnolio *et al.*, “DecoWind: Development of low-noise and cost-effective wind farm control technology,” in *Inter-noise 2022 Noise Control in a More Sustainable Future*, 2022. Accessed: Apr. 12, 2023. [Online]. Available: https://az659834.vo.msecnd.net/eventsairwesteuprod/production-inconference-public/3889aefd315848d6bf9656a24c0a820d
[23] K. Søndergaard, Lars Sommer; Thysell, Erik; Claumarch, Christian; Vignaroli, Andrea; Thomsen, Carsten; Hansen, “Long distance noise propagation over water for an elevated height-adjustable sound source,” *9 th International Conference on Wind Turbine Noise Remote from Europe 18 th to 21st May 2021*, no. May, pp. 1–6, 2021.
[24] L. S. Søndergaard, C. P. Volk, T. R. Hansen, L. Enggaard, T. Sørensen, and A. Pena, “9th International Conference on Wind Turbine Noise,” in *Wind farm neighbourship investigated by a daily app questionnaire combining weather, noise, and annoyance*, Online conference: INCE Europe, 2021, pp. 1–15.
[25] K. Bolin and M. Åbom, “Air-borne sound generated by sea waves,” *J Acoust Soc Am*, vol. 127, no. 5, pp. 2771–2779, May 2010, doi: 10.1121/1.3327815.
[26] K. Bolin, “Prediction method for wind-induced vegetation noise,” *Acta Acustica united with Acustica*, vol. 95, no. 4, pp. 607–619, Jul. 2009, doi: 10.3813/AAA.918189.
[27] S. Cooper, T. Acoustic, and G. Pty, “Hiding Wind Farm Noise in Ambient Measurements - Noise Floor , Wind Direction and Frequency Limitations,” in *5th International Meeting on Wind Turbine Noise*, 5th International Meeting on Wind Turbine N, 2013.
[28] M. Terlich, “The Case for Spectral Measurements of Ambient Noise Levels in the Assessment of Wind Farms,” *Fourth International Meeting on Wind Turbine Noise*, no. April, pp. 1–6, 2011.
[29] D. Mennitt, K. Sherrill, and K. Fristrup, “A geospatial model of ambient sound pressure levels in the contiguous United States,” *J Acoust Soc Am*, vol. 135, no. 5, pp. 2746–2764, May 2014, doi: 10.1121/1.4870481.
[30] H. F. Boersma, “Characterization of the natural ambient sound environment: Measurements in open agricultural grassland,” *J Acoust Soc Am*, vol. 101, no. 4, pp. 2104–2110, Apr. 1997, doi: 10.1121/1.418141.