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Amplitude Modulation and Complaints about Wind Turbine Noise

Joachim Gabriel, Steffen Vogl, Thomas Neumann, DEWI GmbH (German Wind Energy Institute), Wilhelmshaven, Germany,
E-mail: j.gabriel@dewi.de, s.vogl@dewi.de, t.neumann@dewi.de

Gundula Hübner, Johannes Pohl Research Group Health and Environmental Psychology, Institute of Psychology, Martin-Luther-University Halle-Wittenberg, Germany
E-mail: johannes.pohl@psych.uni-halle.de

Summary

Amplitude modulated aerodynamic noise turned out to be the common ground of complaints documented within a research project about acceptance of noise from wind turbines (WT). The assessment method combined interviews with residents of a wind farm with physical measurements. Audio recorders had been handed out to residents to record annoying noise situations by themselves, as it is difficult to perform a temporary measurement just at the time of annoyance and complains about WT noise.
Available data did not allow the definition of a certain critical operational mode or weather condition for AM, but daytime patterns occurred.
An AM assessment tool for the quantification of AM-perception has been developed and applied to the sound recordings.
An improved version of the AM assessment tool - featuring long term data analysis - will help to identify AM critical operational conditions.

1 Introduction

With a growing number of installations, operators of wind farms are confronted with an increasing number of complaints about noise from WTs. But what makes residents complain? Is there any correlation of complaints and certain weather conditions? Is there a way to change the sound performance of a wind farm in order to improve the acceptance? To answer these questions the German research project [1] funded by Deutsche Bundesstiftung Umwelt (DBU, German Federal Foundation for Environment) combines interviews with residents of a wind farm and physical measurements. With the focus on physical aspects this paper will present findings from evaluations of this data base.

2 The Project

The subject matter of the project is a wind farm of 9 two-megawatt-WTs in Northern Germany at a distance of approximately 1500 m from a village in rural flat landscape. The hub height is 108 m.

Assuming sound power levels according to the information supplied by the WT manufacturer, sound propagation calculations result in sound pressure levels below 33 dB(A) for houses near the wind farm.

In March 2012, 212 residents were interviewed using a questionnaire with 450 items and got forms to document complaints about noise from the wind farm (22 items). Audio recorders were available in order to document times with annoying sounds from the turbines. These recordings have been listened to and analysed in addition to temporary standardised noise measurements. Meteorological - and WT-data, derived from the WT controllers and an independent data acquisition system, were recorded for the whole time of the campaign.

The data basis for the analysis were standardised complaint forms, acoustical data and minimum / maximum values as well as 10- minute averages of wind speed at hub height and at 10 m height, wind direction, active power, and rotational speed for each WT.

Figure 1: Residents view on the wind farm

3 Measurements and Evaluations

Figure 2: Acoustic noise measurements near the wind turbines

Standardised measurements according to IEC 61400-11 Ed.2.1 show no indication of any unexpected acoustic noise emission of the WTs and sound power levels used for the sound propagation calculation were proved within the measurement uncertainty.

Figure 3: Acoustic noise measurements at a noise receptor location

Temporary acoustic noise measurements according to DEWIs accredited standard were performed at one of the houses relatively close to the wind farm. As expected because of the distance to the WT and the level of the masking noise, resulting sound pressure levels for the wind farm operating and stopped showed no difference.

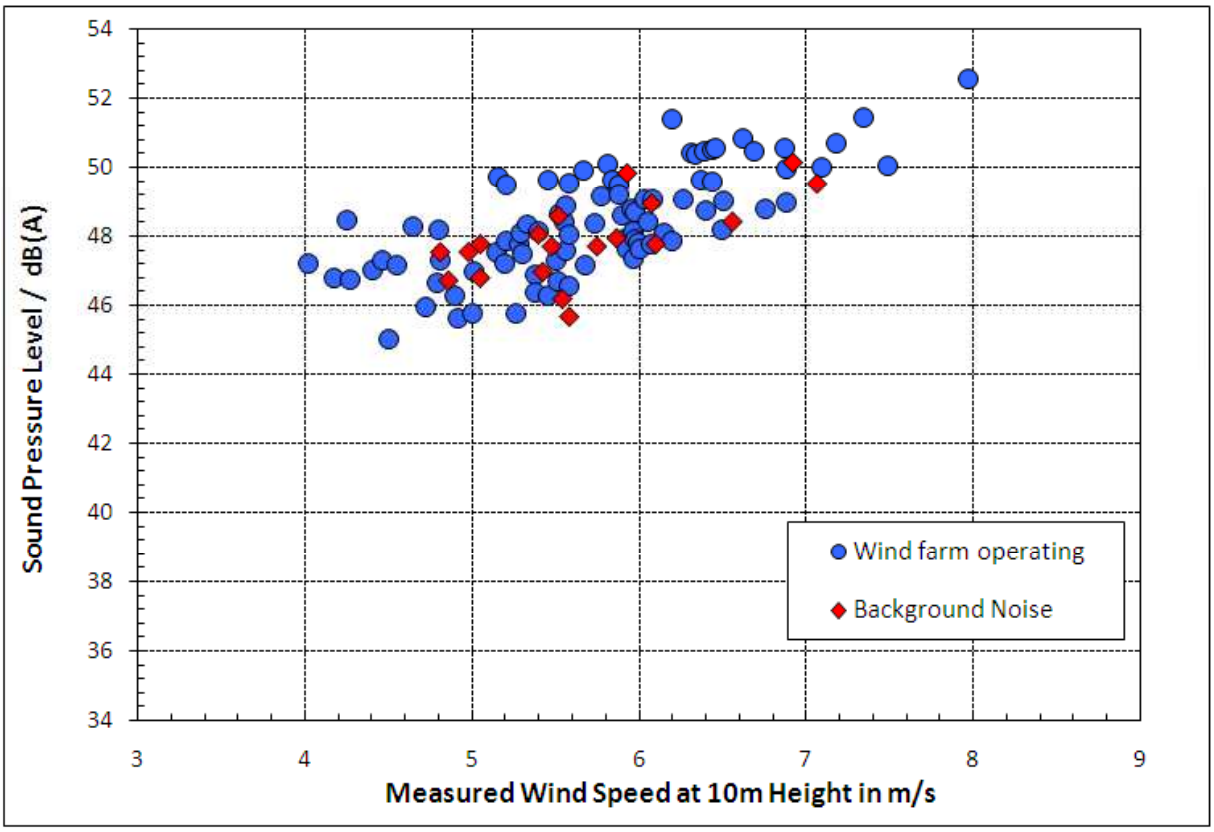

Figure 4: Results of measurements at a noise receptor location

Because of the high level of background noise additional measurements closer to the wind farm were performed. The result was a better signal to noise ratio but being different from the sound perception of the residents, the recordings did not help to understand the complaints.

Figure 5: Additional measurement location using a vertical board according to [2] to get a better signal to background noise ratio

According to the project data and the results of measurements and evaluations there is no indication for any noise immission problems with regard to the German immission protection law. Compared to other German projects the WTs are installed at a relatively high distance to the houses and sound pressure levels are likely to be far below legal limits. Never the less residents complain about the noise from the wind farm and there even have been judicial proceedings.

Until January 2013 a total number of 95 complaints by 10 residents were documented. Figure 6 shows the time series of wind directions associated with these complaints. 80 % of the complaints occurred at night or early morning.

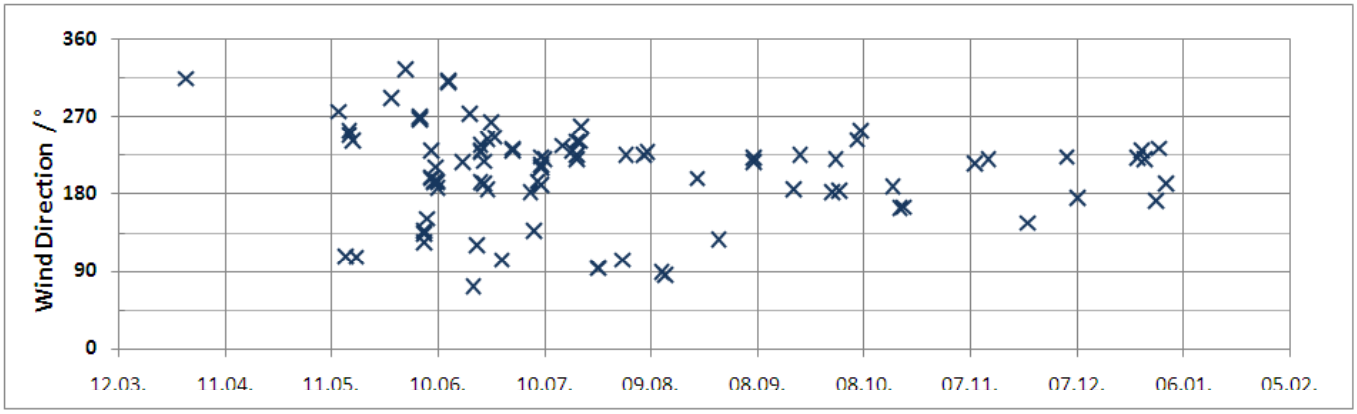

Figure 6: Wind direction for times of complaints

There is an accumulation of complaints after the initial presentation of the project at a public meeting and a maximum for the wind direction distribution for wind from south-south-west, which is more or less the main wind direction for the site. This wind direction represents downwind situations for almost all complaints. But there are also some “upwind-complaints”.

The complaints were also associated with wind speeds and rotor rotational speeds. As demonstrated in Figure 7 there is no striking accumulation neither for minimum, maximum nor average values of the wind speed.

Neither for a wind direction or speed nor for a rotor rotational speed a outstanding complaint frequency can be derived from the data.

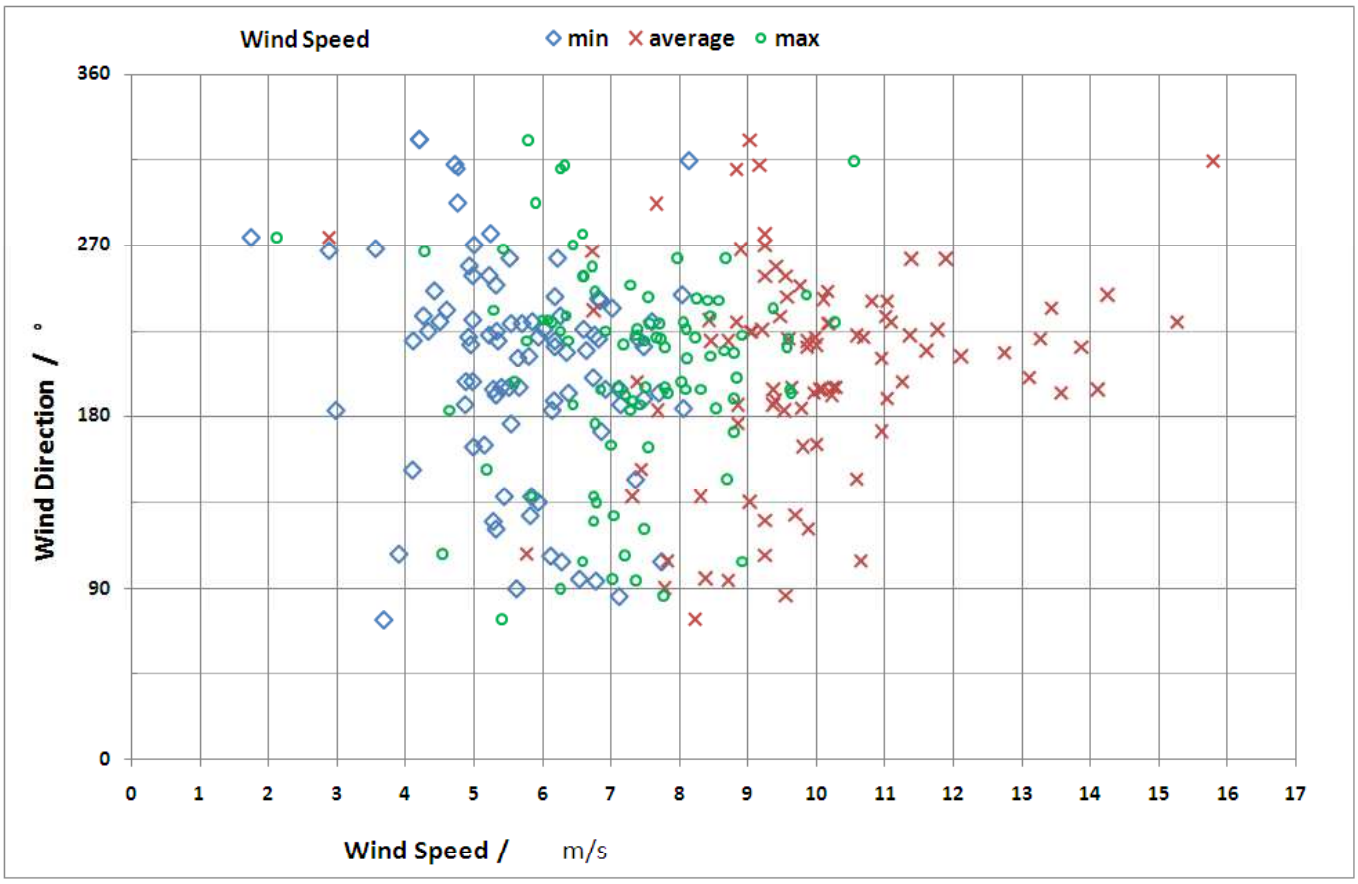

Figure 7: Wind direction versus wind speed for all complaints

The data base did not allow the definition of a certain critical operational mode or weather condition for complaints, but daytime patterns occurred. Most of the complaints were made during the night for low background noise conditions.

4 Amplitude Modulation as Common Ground of the Complaints

As to this wind farm, it is not the loudness of the broadband WT-noise causing complaints, nor is it tonality or impulsivity - at least according to standardised definition of impulsivity. Interviews and sound descriptions in the complaint forms summarized in table 1 show, that residents complain about sound identified as different from the “natural” background noise, even if the loudness of this special sound is very low and hardly perceptible.

Thus the common ground of the documented complaints is a WT-specific sound characteristic perceived by humans, and directly correlated to the rotation of the rotor blades. This is nothing new for people who deal with complaints about noise from wind turbines. This sound - described as swishing in the frequency of the rotor blades - is amplitude modulated aerodynamic noise of the WTs (AM).

Description as modulated noise (e.g.: loud pulsating noise; Pfsch - Pfsch - Pfsch ...)	**68**
Description unclear regarding modulation (e.g.: hissing, roaring, recurring, irregular ...)	**21**
Description as a constant noise (e.g. constant noise, aircraft noise constantly)	**6**
Total number of complaint sheets	**95**

Table 1: Evaluation of complaint sheets with regard to AM

Whereas there are studies and findings about amplitude modulation (AM) in the near field, research on long distance AM faces the difficulty that AM is hard to identify in measurements. Currently there are no filters for automatic measuring techniques available. As for every acoustic noise measurement far from the WT the level of turbine noise can be very close to the background noise. Thus one cannot prove if results refer to noise from the wind farm, unless by listening.

It is difficult to get relevant professional recordings of far field AM by temporary measurements. A common scenario for temporary professional sound measurements at houses of people complaining about noise from WTs is the comment “You have come the wrong day. Yesterday it was hard.” And in fact we were told something like this the day we performed our temporary measurement at the selected receptor location. Therefore it turned out how important it was that audio recorders had been handed out to residents to record annoying noise situations by themselves. In addition to our own measurements a total number of 28 of these wav-files was available to assess far field AM.

In order to get an idea of frequency, duration and intensity of AM in wind turbine noise, the audio files have been listened to and analysed by a numerical evaluation tool documented in [3]. Within the tool the modulation depth ΔL was used as a parameter for AM. The modulation depth ΔL is defined as the difference between the maximum and minimum sound pressure level. In addition a second parameter for AM quantification - fluctuation strength F* - was used. F* is a psycho acoustically motivated measure, representing the perceived AM. The origin of F* is the fluctuation strength, developed by Zwicker [4], which was slightly modified for the analysis of wind turbine noise.

Figure 8 shows the analysis of one of the 28 sound samples. Modulation depth ΔL was used as parameter for AM. The black line is the A-weighted 1/3 octave band spectrum of the sound pressure level.

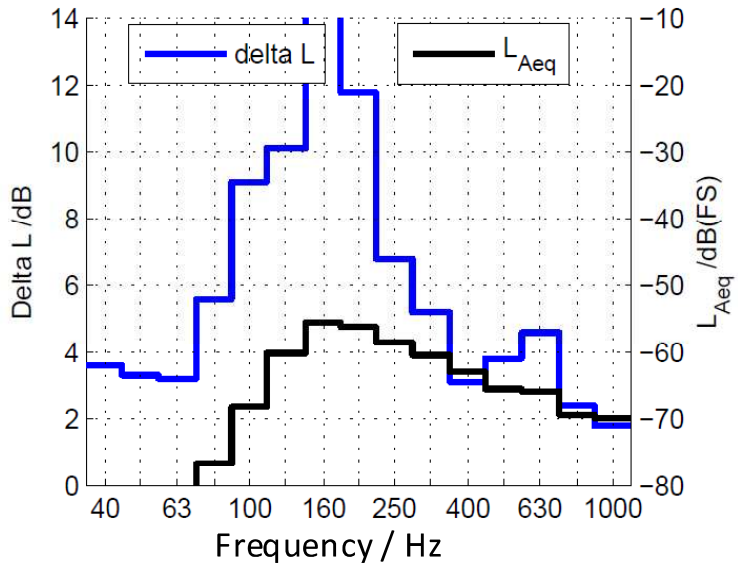

Figure 8: Example of spectrum and evaluated modulation depth of wind farm noise recorded by residents

An example for a resulting time series of modulation depth ΔL and fluctuation strength F* is given in Figure 9.The assessment tool developed for this project produces a reasonable correlation between increased values for ΔL and F*and the subjective impression of AM perception of a human listener. However the tool cannot distinguish between AM caused by a WT or by human voices and birds. Therefore human listening remains necessary.

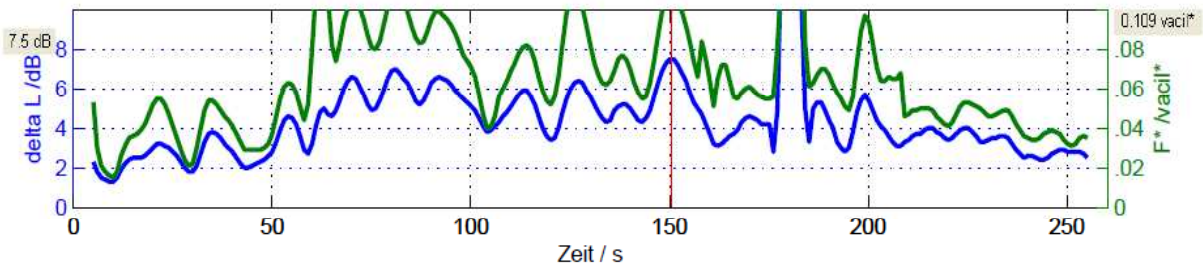

Figure 9: Example of a time series for AM

The audio file of Figure 9 was recorded at 03:20 am and is the only record of 28 showing AM longer than one minute. In the other recordings a clearly perceptible AM only occurred for short time periods (typically < 10 s) or was not at all audible. But it must be noted that the recordings are just snapshots and no statement about the sound situation “beyond the record” can be made.

Evaluated modulation frequencies of 0.7 Hz to 0.9 Hz correspond to rotational speeds of the WT rotor of 14 to 18 rpm.

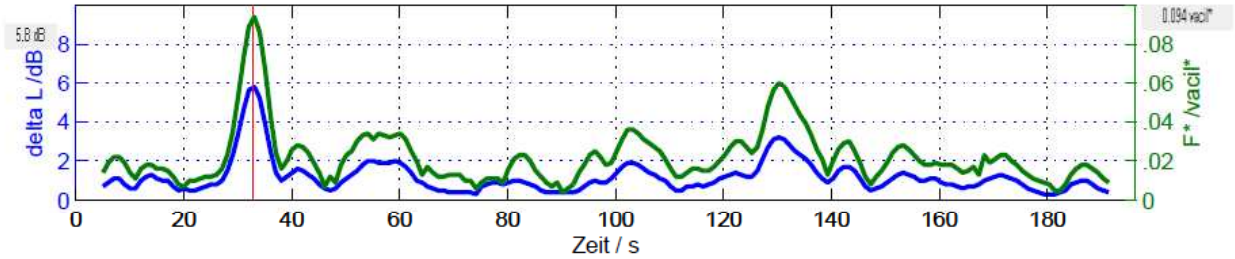

Figure 10: Example of a time series with short AM events

Figure 10 shows only two short time periods of less than 5 seconds of relevant AM. If it was possible to identify the critical conditions for this temporary occurrence of clearly perceptible AM we might come from an all night noise mitigation to just some seconds (or cumulated some minutes for a night) of effective necessary intervention to avoid complaints.

5 Interpretation of AM noise perception

The recordings produced within this project are a unique but still insufficient data base for final conclusions. Within this limited range of the study we find that even a short period with noticeable amplitude modulation might trigger the attention and focuses it on the sound of the wind farm. The sound perception may remain focused on the wind farm noise, even when the amplitude modulation has fallen again below the perception threshold.

Modulation frequencies in the range of 1 Hz don't fit exactly the maximum human sensitivity for modulation at 4 Hz but still might cause a kind of "alarm", explaining the comment of a resident, saying that he wakes up the night because of conspicuous wind turbine noise. In the example of figure 8 he might wake up with the first peak of AM not knowing this was the reason, but half awake and listening if there might be some "danger". He might identify the wind farm as origin of noise with the next "peak" of AM and from now on it might be hard for him to rest or to fall asleep again.

According to this, complaints could be reduced if it was possible to eliminate the short "Trigger-AM". Assumed relevant AM mainly only occurs for short time, loss of energy will be very small compared to the common mitigation method with the WTs operating all night in a noise reduced operational mode.

6 Ideas for Mitigation of the Annoyance

Noise reduced modes usually base on reduction of the rotational speed of the WT rotor. How this effects far field AM is unknown. Based on investigations of mainly near field AM, reduction of trailing edge noise is in the focus when thinking of AM mitigation. With regard to the above described findings, there are some more ideas for AM mitigation.

If AM as an attention trigger is a short time phenomenon investigations of the causes of far field AM are worth to be carried out. It is likely necessary to look at dynamic aero acoustics as well as wake effects, sound propagation and WT interaction in combination to understand this dynamic phenomenon. Once AM-critical operational modes or sound propagation situations are identified specific modification can reduce or extinguish AM.

Another idea can be described as “sound design”. As it is more the “quality” than the “quantity” of the wind turbine sound that causes complaints, it is conceivable to achieve an equalization of the WT noise either by single blade pitching or even by active generated synchronised broadband noise.

Hearing experiments [3] showed that AM is most annoying at 4Hz. Therefore reduction of rotational speed might reduce complaints.
In the other direction we might also use the above mentioned active systems to get resulting modulation frequencies significantly higher than 4 Hz. The sound would then no longer be associated with the optical impression of turning rotor blades.

7 Next Steps

Rating scale for the efficiency of any mitigation action must be a reproducible method for AM assessment which takes into account that human AM sensitivity is frequency dependend. It can help to objectify the discussion about a WT specific annoying sound characteristic. Especially because AM of WT noise is often mixed up with impulsivity and infra sound. There are examples of AM being regarded as impulsivity even in legal proceedings and infra sound discussion might just be a confusion of modulation frequency and spectral frequency.

In addition to previous work of e.g. Jeremy Bass [5] the above mentioned DEWI software tools might be a start for standardisation. The idea is to develop a standard for an objective assessment of AM in noise from WTs comparable to the German DIN 45681 for tonality. It must be emphasized that this standard is for noise at receptor locations only and must not be mixed up with “near field” guidelines like IEC 61400-11. The discussion of AM standardisation is on the agenda of the national German WT noise work group.

Next step for the above mentioned project will be a test of a special operational mode proposed by the WT manufacturer to reduce annoyance. Based on interviews of affected persons the efficiency of the mitigation method will be evaluated. But as the design strategy for this special operational mode is not focussed on AM mitigation this might be only a first step and there are signs that a number of WT manufacturers work on intelligent AM mitigation solutions.

Still there is a couple of questions about far field AM which might be answered by means of a far field sound recording station and automised assessment tools, e.g. based on an improved version of the one presented. With the help of AM audibility data and in correlation with high resolution meteorological and WT data manufacturers of WT can improve their knowledge about AM and optimize the sound performance of their turbine.

References

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Gundula Hübner, Johannes Pohl, Research Group Health and Environmental Psychology, Institute of Psychology, Martin-Luther-University Halle-Wittenberg;
Joachim Gabriel, DEWI GmbH (German Wind Energy Institute);
funded by Deutsche Bundesstiftung Umwelt (DBU, German Federal Foundation for Environment), wpd windmanager

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