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

D1.6 Proposal for new regulations for wind turbine noise – summary results from WP1 (M30)

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Executive summary

Based on results of long-term noise monitoring and laboratory experiments we estimated the relation between noise annoyance ratings and sound level of wind turbines noise. The sound level at which noise annoyance is equal to 4 was observed to be 44.3 dB. Taking some assumptions about maximum acoustical power and wind conditions we also derived noise limits for L_{DEN}, L_N and equivalent sound levels.

Authors	Date of submission	Confidentiality level
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As it was defined in the WP objectives, we wanted to establish a relationship between noise annoyance ratings and sound level values of wind turbine noise. We planned to use a cutoff at ICBEN value equal to 4. It means that the noise limit should be set at the level at which ICBEN rating is equal or greater than 4.

The crucial factor is to establish noise limits expressed in both short and long-term noise indices. Thus, in forthcoming sections we will present our recommendations regarding values of L_{DWN},[1] L_N , $L_{Aeq,D}$ and $L_{Aeq,N}$.

L_{DWN} recommendation[1]

Based on field recordings recorded near one of the wind farms in central Poland we conducted a laboratory experiment in which people (n = 34) rated noise annoyance. We recorded wind turbine downwind in 5 different distances: 150, 250, 500, 750 and 1000m. It corresponded also to different sound level values: 49.1, 49.7, 42.8, 38.2 and 36.3 dB respectively.
As a comparison, we presented also road traffic noise, with the same levels. All stimuli lasted 5 minutes, thus, the measured sound level was LAeq,5min. Results of the experiment can be found in Fig. 1. More information about that experiment can be found in our conference paper (Felcyn et al., 2023).

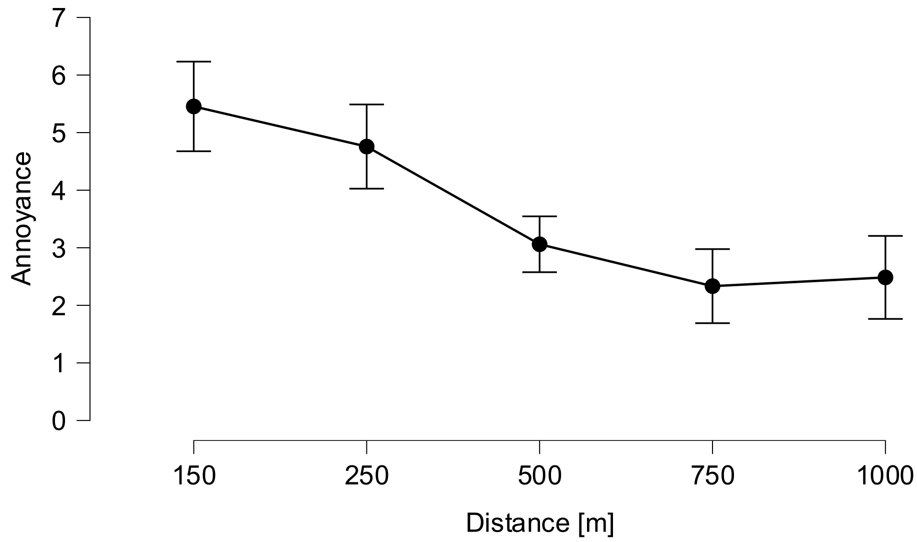

Figure 1. Mean annoyance ratings (with 95% confidence intervals) measured for the wind turbine noise presented in the laboratory experiment.

As one can see, the rating of 4 lies somewhere between 250 and 500 m – that is, between 49.7 and 42.8 dB, respectively. We can then compute the linear regression model which gives the following results (Table 1):

[1] Polish legislations L_{DWN} is equal The Environmental noise directive (END) 2002/49/EC L_{den}

Table 1. Results of linear regression model computed for the noise annoyance ratings and sound level values.

Coefficients						
Model		**Unstandardized**	**Standard Error**	**Standardized**	**t**	**p**
H_0	(Intercept)	3.618	0.177		20.427	6.344×10^{-47}
H_1	(Intercept)	-5.694	1.178		-4.832	3.094×10^{-6}
	SoundLevel	0.219	0.027	0.529	7.968	2.634×10^{-13}

When we take the coefficients values and use annoyance equal to 4, we get the predicted sound level value equal to 44.3 dB. However, it is more common to use the threshold of 45 dB in some Polish law regulations – in that case, the annoyance rating is equal to 4.16.

However, the most common relationship established between noise annoyance ratings and sound level values is the so-called exposure-response function (ERF). As there are several studies regarding wind turbines noise, Michaud et al. gathered data from them and synthesized a function to predict percent of highly annoyed:

$$P_{HA} = 100e^{-\left(\frac{1}{10^{0,1(L_{DWN}-L_{ct}+4,7dB)}}\right)^{0,3}} \quad \text{Eq.1}$$

Where:
P_{HA} is the prevalence of high annoyance (percentage of people being highly annoyed),
L_{DWN} is the time-of-day weighted yearly average noise exposure level and L_{ct} is the Community Tolerance Level for wind turbine noise, L_{ct} = 62.0 dB (ISO, 2016).

According to World Health Organization (WHO), 10% HA is the limit for health effects of noise – and is independent from the noise source. Taking it into account and considering eq. 1, we get the L_{DWN} value of 44 dB. However, WHO in its guidelines recommended to keep the noise from wind turbines below 45 dB (which depicts the %HA = 10.7). This recommendation is in line with our findings – thus, it seems reasonable to set the L_{DWN} limits of wind turbine noise to 45 dB.

L_N recommendation

From literature findings we know that for wind turbine noise there is a strong correlation between annoyance and sleep disturbance. Thus, it seems reasonable to use L_{DWN} values to determine permissible night level L_N . As there is a possibility that only several nights during a whole year would be loud, we should be sure that permissible level would be lower than each of these worst nights.

To predict the case of the worst night we have to make several assumptions:

- The turbine works with its maximum power (thus, the acoustical power is also the highest)

- The receiver point is located in the downwind direction (in the area where the noise is the loudest)

In that case we will get the highest possible value of the L_{Aeq} – we can call it max L_{Aeq}. Any changes in wind speed would effect in smaller acoustical power and thus – in lower L_{Aeq} values.

We have an access to data from three wind turbines regarding electrical and acoustical power, wind speed at hub position as well as noise levels measured in long-term noise monitoring campaign (near one wind farm). Based on gathered data we can compute what is the maximum difference between max L_{Aeq} and L_{DWN}. Assuming that the wind turbine works the whole year with the maximum power, the difference is 6.4 dB. For three analysed wind turbines and three different times (day from 6 to 18, evening – from 18 to 22, and night – from 22 to 6) the difference varies between 6.7 and 4.8 dB.

All these findings lead us to the assumption that for the night time (L_N) the limit should be little below 39 dB. However, to be more consistent with the existing noise limits in Polish law, we can set this requirement to 40 dB without any harm to the situation – because, as we underlined earlier, we assumed that the wind turbine works at maximum power during the whole year.

This recommendation takes into account also findings from ISO 1996-1:2016 that *'in newly created situations (…) higher community annoyance can be expected. (…) In quiet rural areas, this greater expectation for "peace and quiet" may be equivalent up to 10 dB'*.

$L_{Aeq,\mathrm{T}}$ recommendations

Another thing is to develop limits for short-term noise indices, equivalent sound levels measured during day or night. Knowing acoustical power of turbines and our previous computations, we can use Eq. 2 to predict the $L_{Aeq,\mathrm{N}}$ level.

$$L_{Aeq,max} = L_{DWN} - 10 \cdot log\left\{\frac{12}{24}10^{0.1\cdot\Delta L_D} + \frac{4}{24}\sqrt{10}\cdot 10^{0.1\cdot\Delta L_W} + \frac{8}{24}10\cdot 10^{0.1\cdot\Delta L_N}\right\}$$

Eq.2

Taking into account that L_{DWN} = 45 dB and knowing performance characteristics of three wind turbines, we get results that $L_{Aeq,\mathrm{max}}$ is 44.1, 45.2 and 43.6 dB respectively. Thus, the proposal for one night is: $L_{Aeq,\mathrm{N}}$ = 45 dB.

This limit takes into account that closed window with poor insulation decreases the sound slightly more than 20 dB and that the opened window reduces noise by around 10 dB. It is also in line with requirements of the norm PN 87 B-02151/02 on permissible levels indoors.

Switching to 16 hours day period, we should remember that the most important effect of noise during a day is %HA. As we did not conduct an experiment about it, we took data from (Hongisto et al., 2017). In this paper the relationship between L_{Aeq} and %HA (exposure-response relationship) is as in the Fig. 2:

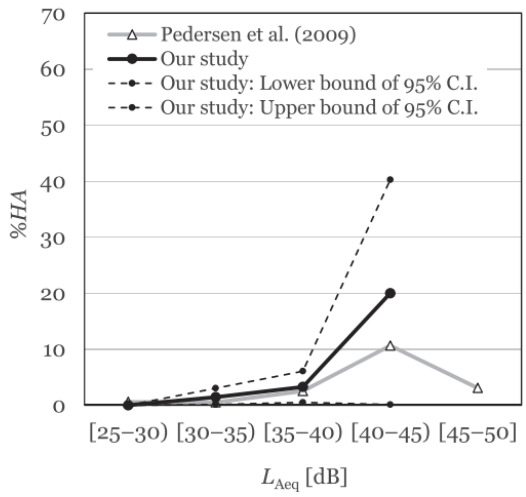

Figure 2. The exposure-response relationship between %HA and L_{Aeq} for wind turbine noise measured in Hongisto et al. 2017 (marked as 'our study') and study by Pedersen et al. (2009).

Once again, as we take 10%HA as the threshold point, the corresponding value of the L_{Aeq} is around 40 dB. However, as we want to establish the limit indoors, we can add additional 10dB (reduction of noise by opened window). Thus, the final recommendation is $L_{Aeq,D}$ = 50 dB.

Please keep in mind that we applied some changes to the existing limits:

- Instead of 1 night hour, we propose to use 8h equivalent sound level $L_{Aeq,\mathrm{N}}$;
- Instead of 8h of day, we propose to use 16h $L_{Aeq,D}$,
- We also want to simplify land use classification. In Polish law there is a split into four different land uses. However, in rural areas (in which wind turbines are most common) this classification is unneeded. Thus, we propose to use only two types of land use instead of four,
- In practice, we increase the limit for night period – as the limit for "all other noise sources" is 5dB lower

We also recommend to use masking effect as the possible way of mitigation of wind turbines noise. When wind turbines are located close to the major roads (like highways) and the road traffic noise is greater than turbines noise, they can be located closer to the sensitive area.

Conclusions – all recommendations

Summing up, we can compare existing regulations in Poland with our recommendations. Right now wind turbines are classified as ‘other noise sources’ and their limits are set to L_{DWN} = 45, 50 or 55 dB and L_N = 40 or 45 dB (according to four different types of land use). Switching to shorter indices, $L_{Aeq,D}$ = 45, 50 or 55 dB and $L_{Aeq,N}$ = 40 or 45 dB (the same four land use types are used).

We recommend to simplify land use classification and have only two different groups:

- 1st category: hospitals and social care homes, buildings related to the permanent or temporary stay for the children and youth, health resort purposes; in this category recommended wind turbines noise levels are: L_{DWN} = 40 dB, L_N = 35 dB, $L_{Aeq,D}$ = 45 dB and $L_{Aeq,N}$ = 40 dB;
- 2nd category: residential development, recreation and leisure purposes, residential and services purposes; L_{DWN} = 45 dB, L_N = 40 dB, $L_{Aeq,D}$ = 50 dB and $L_{Aeq,N}$ = 45 dB.

These recommendations should be taken into account during any procedure of measuring noise of wind turbines, as well as during planning stage.

These recommendations proposed above should be should be considered only taking into account the new measurement methodologies proposed in the guide which will be presented in D.7

References

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