7th International Conference on
Wind Turbine Noise
Rotterdam – 2nd to 5th May 2017

Evaluation of wind farm noise in Switzerland – Comparison between measurement and modeling

Desarnaulds Victor, EcoAcoustique SA Lausanne : desarnaulds@ecoacoustique.ch
Fécelier Ronan, EcoAcoustique SA Lausanne : fecelier@ecoacoustique.ch
Magnin Dimitri, EcoAcoustique SA Lausanne : magnin@ecoacoustique.ch

Summary

The different evaluation-methods for the wind farm noise in Switzerland – computer models (for new wind farm projects) or on-site measurements (for existing wind farms) are often discussed by the concerned authorities and organizations. In order to improve the evaluation of the wind farm noise, this research project aims to compare the current Swiss calculation method with the results of in-situ measurements of a specific wind park.

The measurement's results allow to validate some elements concerning material and instrumentation, the duration to cover the different meteorological conditions, the parameters to be recorded, the relevant periods, as well as the measurement positions. These results show also the limits of the measurement's method. Given the particularity of the site (situation on a ridge with strong wind exposure), it is not possible to extract exactly the wind turbine noise from the background noise, even if the noise of the wind turbine is partially audible in the audio recordings. In this configuration, the measured sound level represents the noise of the wind turbine mixed with the background noise, even after the suppression of other interfering noises. The different methods tested (periods with high audibility of the wind turbine noise, third-band-analysis, statistical analysis) do not allow to isolate clearly the wind farm noise.

Concerning the calculation's results, the Swiss method recommended to determine the wind farms noise is comparable to the ones used in neighbouring countries. All these methods are based on a simplified approach of the noise propagation, which mainly does not take into account the meteorological effects. Due to the application of a special ground-connection-factor, the results of the mandatory Swiss method (ISO-norm 9613-2 – modified according to EMPA recommendation) are usually 1 to 3 dB(A) higher than those obtained with the commonly used international norm (ISO 9613-2).

The comparison between the results of the measurement and the modeling shows that the average global sound level (annual averaged L_{Aeq} for daytime) obtained from the measurements is 7 dB(A) higher than the values obtained by the modeling. If one takes into account the statistical index L_{A90}, the difference is about 4 dB(A). With increasing wind speed (v > 7 m/s) the difference between measurement and modeling is particularly marked. This important discrepancy between measurement and calculation results is mainly due to the fact that the measured wind turbine noise is overrated by the presence of background noise (especially from wind in the vegetation).

In order to optimize the methods of measurement and calculation, it would be necessary to perform a more detailed frequency analysis (FFT). The data should also be completed with complementary measurements in several positions (also in the areas less exposed to wind) while the wind turbine is interrupted (« stop-and-go », procedure unfortunately not possible in the frame of this project) and to extend the procedure to several wind parks.

1. Introduction

The different evaluation-methods of the wind farm noise in Switzerland – computer models (project of new wind farms) or in-situ measurements (as for existing wind farms) are often discussed by the concerned authorities and organizations (federal and cantonal public authorities, Suisse Eole …). For modeling purposes, the FOEN (Federal Office for the Environment) recommends a method based on the EMPA report “Lärmermittlung und Massnahmen zur Emissionsbegrenzung bei Windkraftanlagen” [1]. In Switzerland, there isn’t yet any official measurement method for the evaluation of the wind farm noise.

In order to improve the evaluation of the wind farm noise, this research project aims to compare the current Swiss calculation method with the results of one-site measurements of a wind park. This research project is funded by the Swiss Federal Office of Energy - SFOE (project SI/501150).

2. Measurement

2.1 Methodology

The main objective of the measurement method proposed in this research project is to remain simple (equipment, parameter...) and efficient. In order to take into account all the interfering noises (from rain, wind at the microphone and in the trees) and to improve the representativeness of the results, we use a statistical approach over a long measurement period.

The measurement method has also been defined with a view of being as close as possible to ISO 1996-2: 2007 "Description, measurement and assessment of environmental noise -- Part 2: Determination of environmental noise levels” [2] and NF S 31-010 1996 " Acoustics - Environmental noise characterization and measurement — Special measuring methods » [3]:

- wind with an angle relative to the direction of the receiving source of ± 60 ° during daytime and ± 90 ° during nighttime
- wind speed (measured at a height between 3 and 11 m) between 2 and 5 m/s during daytime and with 0.5 m / s more for the nighttime.
- no strong negative temperature gradient close to the ground.
- no disturbing condition, in particular close to the microphone. It is advisable to avoid making measurements when the wind speed is greater than 5 m/s, or in case of heavy rain.

Before performing on-site measurements, a series of laboratory tests were carried out to validate the equipment, in particular performance according to wind speed of various windscreen models.

For on-site measurement, the two locations are selected on both sides of a wind turbine at a distance of approximately 200 m in the direction of the prevailing winds (South-West, North-East). These positions, however, dictated by local constraints (plot boundary, presence of isolated trees), fulfill the ISO 1996-2: 2007 [4] requirements (in the direction of the prevailing winds) and remain relatively distant from disturbing noise sources as forests and other wind turbines present in the area. Moreover, choosing a position relatively close to the wind turbine allows to reduce the uncertainties related to long distance propagation and the influence of background noise (increase of S/N ratio).

The on-site measurement performed over one month (May-June 2015) covers varied weather conditions, which are representative of those usually found in this area.

2.2 Results

<u>Laboratory</u>

5 windscreen models (windshields available on the market) have been tested in laboratory :

- Standard windscreens (included with the sound level meter Norsonic Nor 140), 60 mm diameter (Nor 1451).
- Standard windscreens 90 mm diameter (Nor 1434).
- Microphone Outdoor Protection Kit (Windshield Nor 1212, 50 mm diameter)
- Large (200 mm) diameter windscreen (Outdoor Microphone Protection System Rion WS 03)
- Double windscreen (Nor 1216 + CA 4575)

The results (see Figures 1 and 2) show that the most efficient systems to limit airflow noise at high speeds (> 5 m/s) are the double windscreen (Nor 1216 + CA 4575) followed by the large diameter windscreen (Rion WS 03). All systems tested are quite equivalent for air velocities lower than 5 m/s.

For typical noise spectrum of a wind turbine, the overall sound level correction (L_{Aeq}) due to frequency response of the double windscreen (Nor 1216 + CA 4575) is +0.3 dB(A), mainly due to high frequencies. No correction is needed for the other windscreen.

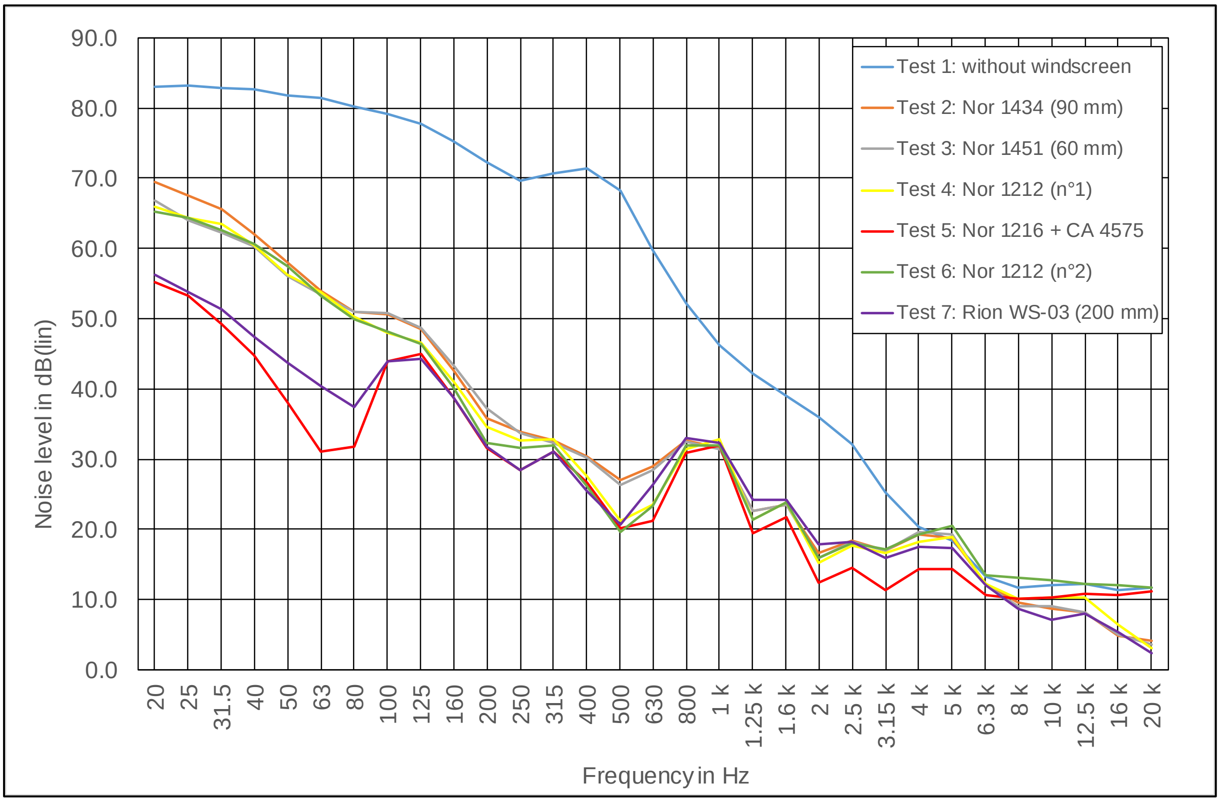

Figure 1 : Frequency level for various windscreens at 4.7 m/s wind speed

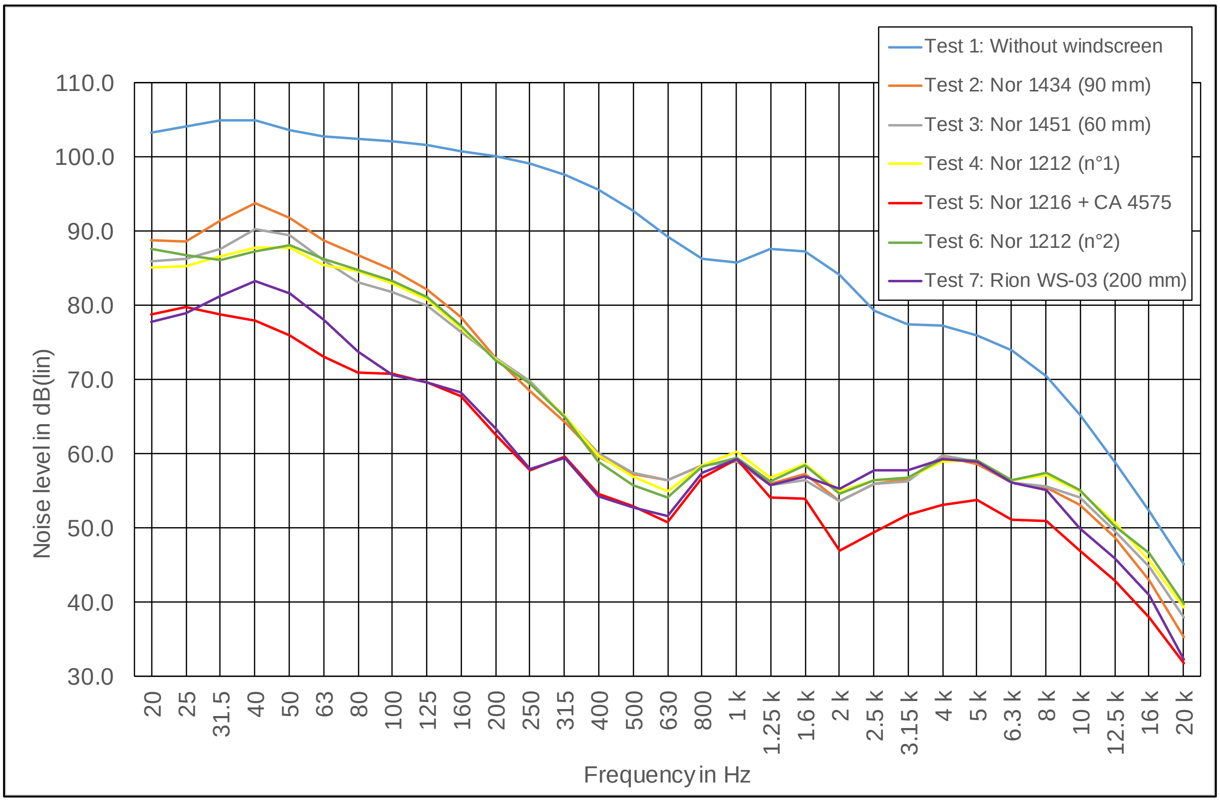

Figure 2 : Frequency level for various windscreens at 12.8 m/s wind speed

<u>On-site</u>

In a first stage, short term on-site measurements are grouped in a single figure for each measuring position (see Figure 3 for position 1). Measured sound levels take into account all sound events that occur near the microphones.

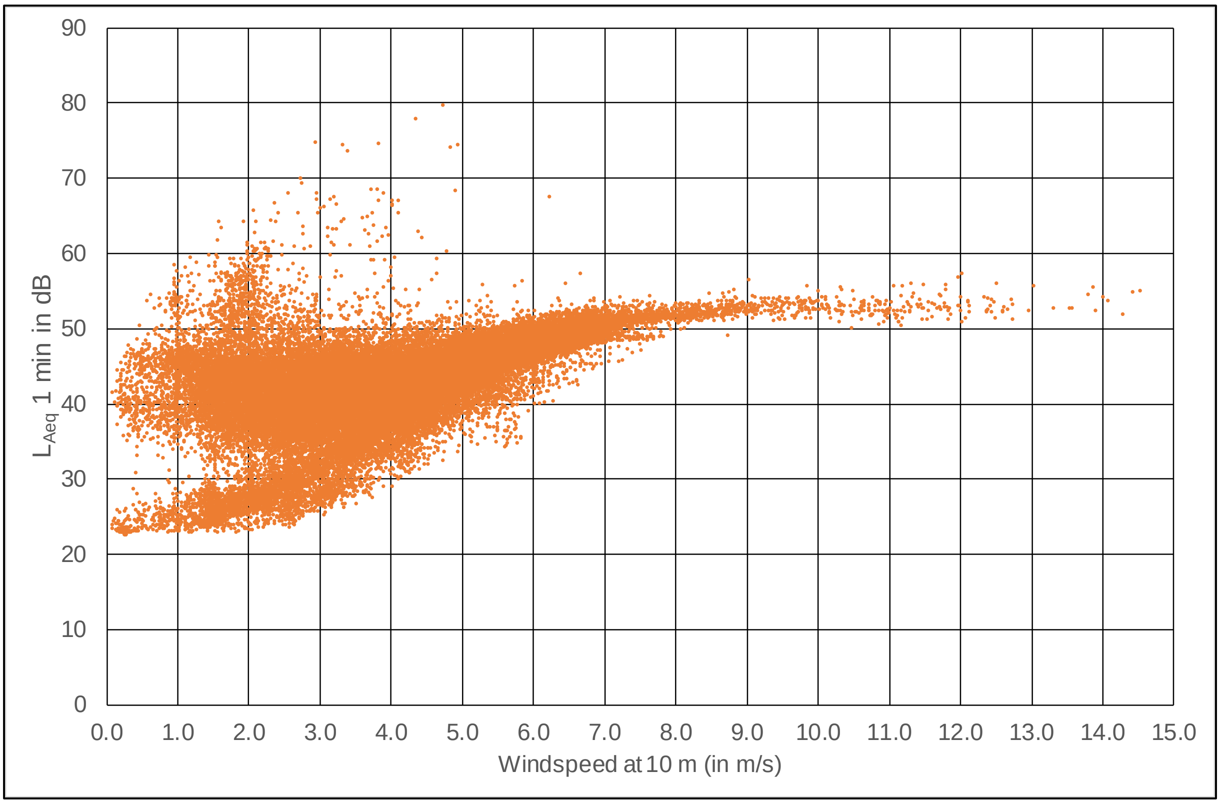

Figure 3 : Raw data of sound level (L_{Aeq}) measured at position 1

In a second stage, in order to extract the useful information, it is necessary to remove disturbing noises due to:

- Unfavorable weather condition (rain, wind gust at the microphone)
- Human activities (tractor, forestry work, construction sites in the vicinity)
- Noise from animals (cow bells, birds, crickets)

Based on post processing analysis of audio recordings, the samples containing such disturbing noises have been removed. The suppression of disturbing noise led us to consider only the measurement results during nighttime (from 22h00 to 4h00) for the rest of this research project (see Figure 4).

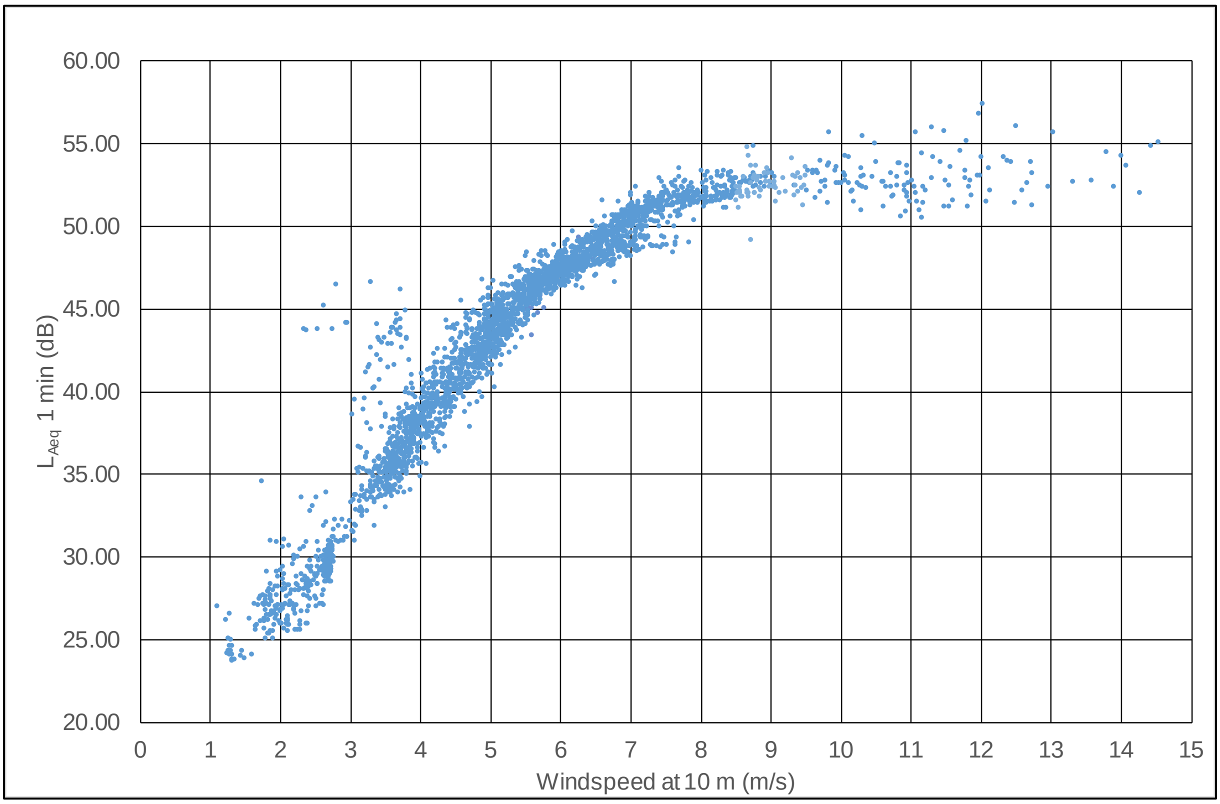

Figure 4 : Selected data (after suppression of disturbing noise) of sound level (L_{Aeq}) measured during nighttime (22h-4h) at position 1 for main wind direction

Based on these selected data, trend curves (third order polynomial) are plotted in order to determine the sound levels for each wind class. Then, the annual average sound levels for day and night periods are calculated based on these trend curves and according to the different wind classes' occurrences (see Table 1).

Windspeed m/s	Sound Level L_{A90}	Day occurrence %	Weighted Day L_{A90}	Night Occurrence %	Weighted Night L_{A90}
<4.5	--	42.9	--	31.0	--
4.5-5.5	43	11.4	34	10.9	34
5.5-6.5	48	9.3	37	10.8	37
6.5-7.5	50	8.2	39	10.1	40
7.5-8.5	52	7.0	40	8.7	41
8.5-9.5	53	6.1	41	8.1	42
>9.5	54	15.1	46	20.4	47
Total		100	**L_{day}=49**	100	**L_{night}=50**

Table1 : Day and night annual average level calculation (L_{Aeq} from sound levels and wind occurrence in each wind speed class, position 1)

Results show that the annual average level is 1 dB(A) higher for nighttime than for daytime. Even with an average occurrence (15 -20%), the highest wind speed class (>9.5 m/s) represents the essential contribution to noise (50%).

However, a detailed analysis of the different periods shows that wind noise at the microphone is always significant when the wind turbine operates at high speed. The only periods when wind noise is low are of course limited to weak wind periods when the wind turbine operates with a relatively low power or is off and thus with reduced noise emissions. The values obtained in Table 1 therefore constitute the measured noise levels of wind turbine noise combined with wind noise at the microphone and residual background noise (especially from wind in the vegetation, even at long distance). Unfortunately, it is not possible, in our specific situation, to extract noise data only due to wind turbine (without any disturbance from background noise) even if such noise is audible in the audio recordings.

According to the methodology adopted in some countries, the use of statistical indicators such as L_{A90} (which represents the A-weighted sound level exceeded for 90% of the measurement period) makes it possible to deduce part of the remaining disturbing noises.

The same calculation is then carried out on the basis of statistical indices L_{A90} level to determine the annual average sound levels for day and night periods (see Table 2).

Windspeed m/s	Sound Level L_{A90}	Day occurrence %	Weighted Day L_{A90}	Night Occurrence %	Weighted Night L_{A90}
<4.5	--	42.9	--	31.0	--
4.5-5.5	39	11.4	31	10.9	31
5.5-6.5	43	9.3	34	10.8	35
6.5-7.5	46	8.2	36	10.1	37
7.5-8.5	49	7.0	38	8.7	39
8.5-9.5	50	6.1	39	8.1	40
>9.5	51	15.1	43	20.4	44
Total		100	**L_{day}=46**	100	**L_{night}=47**

Table 2 : Day and night annual average statistical L_{A90} level calculation (Position 1)

Results with L_{A90} lead to same conclusion as for L_{Aeq} but with values 3 dB lower.

3. Calculation

3.1 Methodology

The application of the internationally recognized noise propagation model ISO 9613-2 [2] to wind turbine noise is problematic because of the important height of such noise sources. For that reason, the FOEN recommends in Switzerland to use the ISO 9613-2 standard with certain adaptations, in particular concerning the ground effect [1]. Various computation models for noise propagation are compared for our particular wind turbine situation (ISO 9613-2 [2], Ljud från vindkraftverk [5], CNOSSOS [6], Nord 2000 [7], Harmonoise [8]).
Except for the simplified Swedish method ([5]), they are all quite similar to the ISO 9613-2 method.
Computer modeling is also carried out using CadnaA software (version 4.2) with 3D terrain model including vegetation and wind turbines as omnidirectional noise sources.

3.2 Results

Calculation results according to the various models and parameters (Ground factor G from 0 to 1) are summarized in Table 3 and Figure 5. The average annual sound levels of the various calculation methods is 42 dB(A) ± 2 dB(A), except for the Harmonoise max method (Class S5) with slightly higher results (45 dB(A)).

Wind speed m/s	Day Occurrence %	ISO 9613 (EMPA)	ISO 9613 (G=0)	ISO 9613 (G=0.5)	ISO 9613 (G=1)	Ljud från vindkraftverk (G=1)	CNOSSOS (G=1)	Nord 2000 (G=1)	Harmonoise (G=1)
4.5-5.5	11.4	38.7	40.8	39.3	37.9	40.3	37.0	39.2	39.5 -> 41.9*
5.5-6.5	9.3	42.8	45.0	43.5	42.0	44.5	41.1	43.4	43.7 -> 46.1*
6.5-7.5	8.2	44.7	46.9	45.4	43.9	46.3	43.0	45.3	45.4 -> 48.8*
7.5-8.5	7.0	45.4	47.6	46.1	44.6	47.1	43.7	46.0	46.1 -> 49.5*
8.5-9.5	6.1	45.5	47.7	46.2	44.7	47.2	43.8	46.1	46.2 -> 49.6*
>9.5	15.1	45.1	47.3	45.8	44.4	46.8	43.4	45.7	45 -> 48.3
Annual LAeq daytime		**42**	**44**	**42**	**41**	**43**	**40**	**42**	**42 -> 45**

Table 3: Annual average noise level calculated for position 1 with the various models and parameters (Ground factor G from 0 to 1)

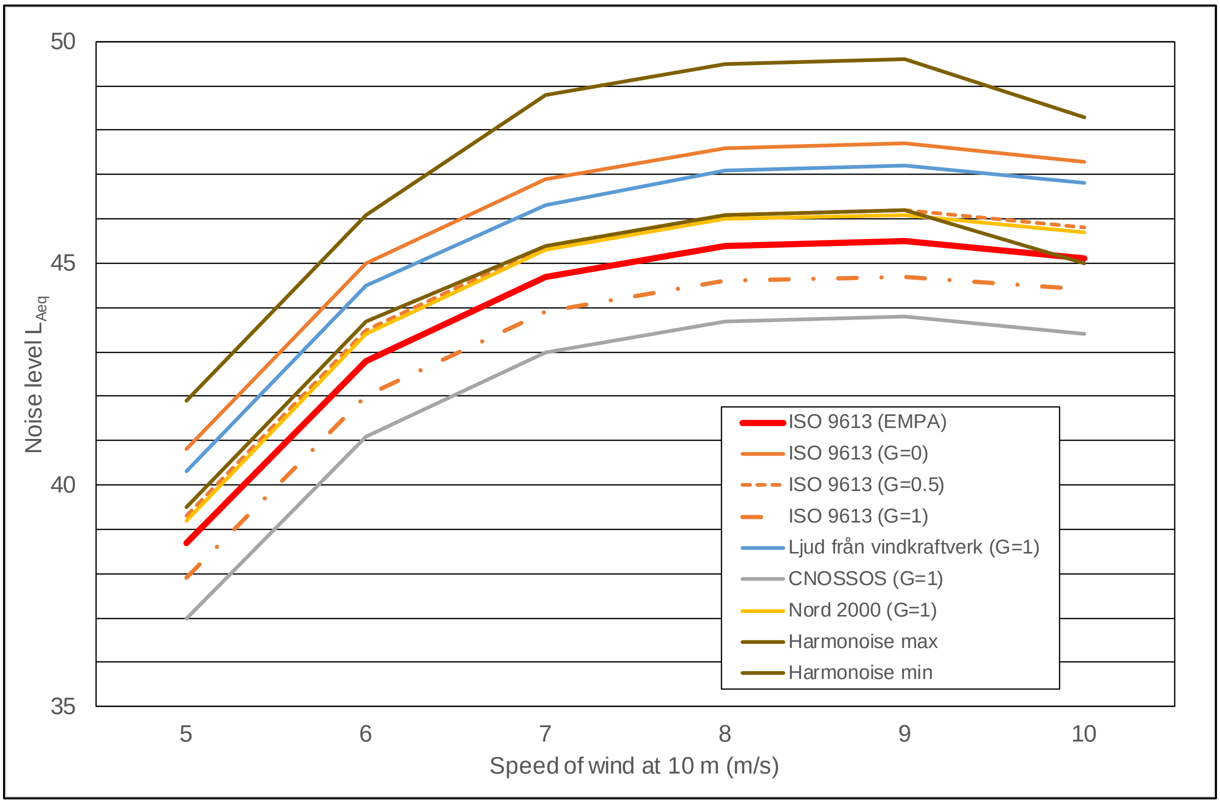

Figure 5 : Noise level according to wind speed calculated with the various models and parameters (Ground factor G from 0 to 1)

The modelling's results show that:

- Most of the calculation methods tested do not take into account meteorological effects (except for the Harmonoise method). The noise propagation is therefore considered to be independent of wind speed and direction.
- The results of the different calculation methods are within ± 2 dB(A) (except for Harmonoise Class S5). This range is relatively small compared to the uncertainties associated with this type of calculation (between -6 and +3 dB (A) according to the EMPA [1]).
- The Swiss method (EMPA) differs from other models, using a single correction factor for the ground effect (+1 dB).

4. Comparison between measurement and calculation

The comparison between measurements and modeling is illustrated in Figure 6 and Table 4.

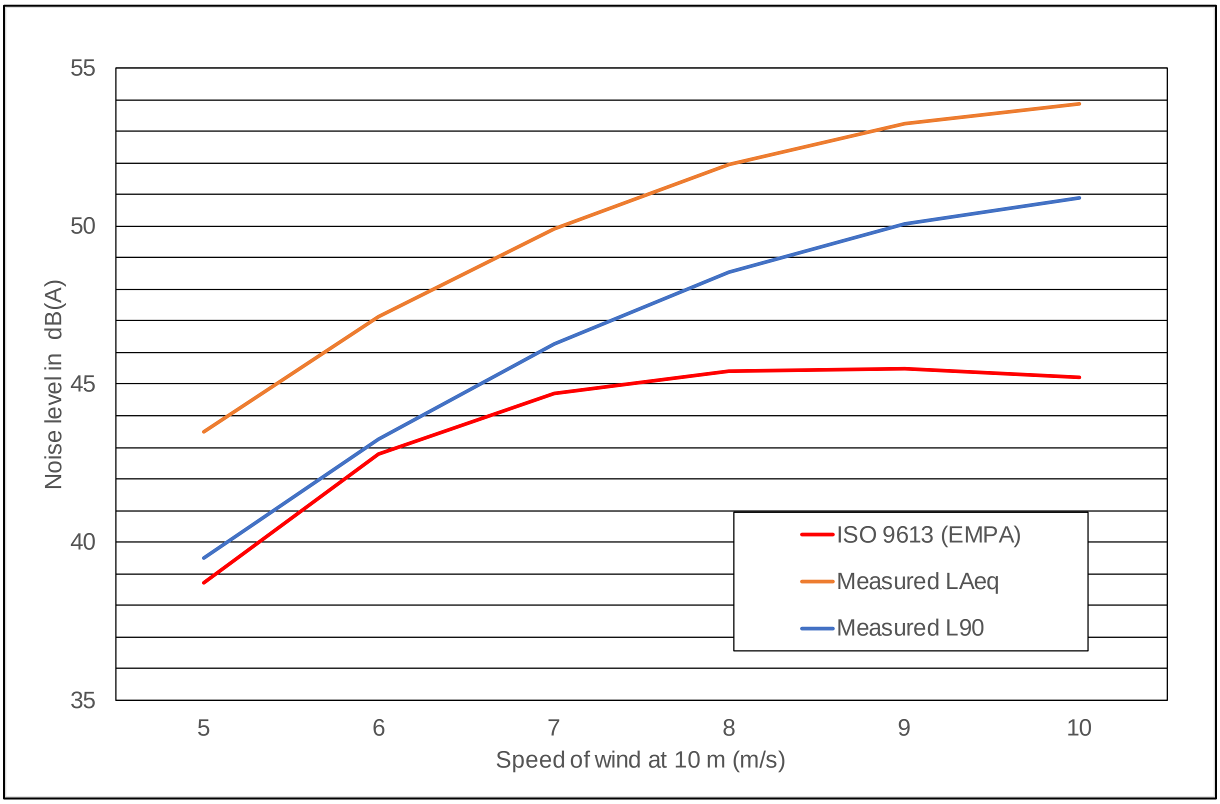

Figure 6 : Calculated and measured sound level according to wind speed and direction (position 1)

Daytime, Position 1	dB(A)
Measurement, annual L_{Aeq}	49
Measurement, annual L_{A90}	46
Calculated L_{Aeq} (ISO 9613-2 including Empa correction)	42

Table 4 : Summary of measured and calculated annual average levels (daytime, position 1)

The average sound levels (annual L_{Aeq} for daytime) obtained by measurements are 7 dB(A) higher than the calculated results. When taking into account the L_{A90}, the difference is only 4 dB(A). The difference between measurements and modeling increases with the wind speed and becomes very significant at high wind speed (v> 7 m/s).

This large discrepancy between measured and calculated results is mainly due to the fact that the measurements results include not only wind turbine noise but also some residual background noise (mainly due to wind noise in the vegetation), which cannot be extracted.

5. Conclusions

The comparison between the results of the measurement and the modeling shows that the average global sound level (annual averaged L_{Aeq} for daytime) obtained from the measurements is 7 dB(A) higher than the values obtained by the modeling. If one takes into account the statistical index L_{A90}, the difference is about 4 dB(A). With increasing wind speed (v > 7 m/s) the difference between measurement and modeling is particularly marked.

This important discrepancy between measurement and calculation results is mainly due to the fact that the measured wind turbine noise is overrated by the presence of background noise (especially from wind in the vegetation). In order to optimize the methods of measurement and calculation, it would be necessary to perform a more detailed frequency analysis (FFT). The data should also be completed with complementary measurements in several positions (also in the areas less exposed to wind) while the wind turbine is interrupted (« stop-and-go », procedure not possible in the frame of this project) and to extend the procedure to several wind parks.

References

[1] EMPA, Untersuchungsbericht Nr. 452'460, Lärmermittlung und Massnahmen zur Emissionsbegrenzung bei Windkraftanlagen, Dübendorf, 22. Januar 2010.

[2] Norme ISO 9613-2 (2007) *Description, measurement and assessment of environmental noise -- Part 2: Determination of environmental noise levels*.

[3] Norme francaise NF S 31-010 (1996), *Environmental noise characterization and measurement — Special measuring methods*.

[4] Norme ISO 1996-2:2007, *Méthode générale pour le mesurage du bruit à l'extérieur*.

[5] Ljud från vindkraftverk, Naturvårdsverket, rapport 6241, décembre 2011.

[6] Common Noise Assessement methods in Europe (CNOSSOS-EU), report EUR 25379 EN, 2012.

[7] Nord 2000, Comprehensive outdoor sound propagation, Model Part1: Propagation in an atmosphere without significant refraction, revised 31 march 2006.

[8] SALOMONS Erik, VAN MAERCKE Dirk, DEFRANCE Jérôme, DE ROO Foort, *The Harmonoise sound propagation model*, 22 January 2010.