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Comparative analysis of wind turbine noise assessment and rating procedures in the UK, France and the Netherlands

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Summary

In the recent years, several West-European countries have issued regulations to limit the impact of wind turbine noise, of which some of them also developed specific noise assessment methods to measure and enforce these environmental regulations.

In this paper, the noise assessment methods of the Netherlands, the United Kingdom and France are analysed and compared. Per country, this paper gives a short summary of the noise assessment method and the development of this method, checks if there is a final version of the wind turbine noise assessment method, and if there are remarks published by the acoustical community.

More specific, the Dutch *Reken- en meetvoorschrift windturbinegeluid - annex 4 activiteitenbesluit* (January 2011), the British *ETSU-R-97* and the *A good practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise* (May 2013) and the French *NF S 31-114 Mesurage du bruit dans l'environnement avec et sans activité éolienne – draft 3* (7 July 2011).

These international examples show that the development of noise assessment methods is complex, but possible. Although differences (in the statistical processing of data, in measurement duration and location, ...) exist and technical uncertainties are waiting to be solved (for example dealing with wind-induced noise), analysis shows there are also a lot of similarities between the noise assessment methods (allowance of manual removal of non-representative data such as periods of rain, use of windscreens, use of class 1 noise measurement equipment, ...) of the different countries. This can be useful in the future development or refinement of these procedures.

1. Introduction

Wind turbines can impact their environment in multiple ways. One of the most important environmental impacts is noise (and the corresponding noise annoyance). In many regions, public objections to the siting of wind turbine on land are raised due to the impact of noise near dwellings.

Sound of wind turbines is mainly generated by the movement of rotor blades through the air at high speed. This causes a noise-like, repetitive sound, which can be perceived as annoying.

In the past years, several countries or regions have issued regulations to limit the noise of wind turbines, often based on the existing regulations for industrial noise. Some of these countries also developed specific noise assessment methods and rating procedures in order to measure, limit and enforce these new environmental regulations for wind turbines, or are currently in the process of developing these methods.

2. Experimental design

2.1 Concept

In this paper, the wind turbine noise assessment and rating procedures of the Netherlands, the United Kingdom and France are analysed and compared. Furthermore, the current state of affairs concerning these methods and development stage is discussed.

2.2 France

2.2.1 Overview

On 26 August 2011, the French Government approved new environmental regulations for wind turbines (French Government 2011a). Together with the new environmental regulations, a preliminary wind turbine noise assessment and rating procedure was published (NF S 31-114 – juli 2011). This preliminary standard is the official measuring method, until six months after the final version is published. The preliminary standard determines the noise limit of a wind farm, which is mainly based on the background noise. The final version of this standard is currently in development and is, according to the French national organization for standardization AFNOR, expected in March 2016 (AFNOR 2105).

2.2.1 New environmental regulation for wind turbines in France

Similar to the noise regulations for industry (*installations classées pour la protection de l'environnement*, or ICPE) (French Government 2015), the new noise regulation for wind turbines in France is based on an allowed exceedence of the prevailing background noise ('émergence'). Three criteria are set in the new French noise regulations for wind turbines:

- The noise immission of wind turbines at dwellings may not be higher than 35 dB(A), or, the background noise may not be exceeded with more than +5 dB(A) during the day (7h-22h) and +3 dB(A) during the night (22h-7h);
- Within a specific perimeter near a wind farm, the maximum noise level may not exceed 70 dB(A) during the day and 60 dB(A) during the night;
- Tonality (as stated in point 1.9 of the order of 23 January 1997 (French Government 2011c)) may not prevail for more than 30% of the night period or day period.

Additionally, a distance of at least 500 m between the wind turbines and dwellings or residential areas is required in the new environmental legislation. The regulation also states that the minimal distance to ICPE-installations or nuclear installations needs to be 300 m.

The new regulation references also to the Circular of 29 August 2011, in which the area public inquiry is extended to 6 km around a wind farm (French Government 2011d).

Next to that, an adjustment variable was introduced in the new legislation, which allows the noise limit to be exceeded for a certain amount of time. Due to this adjustment variable, the noise limits may be raised with +1, +2 or +3 dB(A) when the exceedence occurs for a period of 8 to 4 hours, 4 to 2 hours or 2 hours to 20 minutes respectively.

2.2.2 Noise assessment method of wind turbine noise (NF S 31-114)

The French noise assessment method was published in July 2011 as preliminary draft. In this paper, '*NF S 31-114 Mesurage du bruit dans l'environnement avec et sans activité éolienne - version du 7/7/2011 – v3'* is considered (French government 2011b).

This draft noise assessment standard describes the method to measure and analyse the noise levels around wind farms. The standard states how noise levels and wind speeds should be measured and analysed, including statistical analysis to assess the noise level per wind class and determination of the uncertainties involved in determining this wind class.

The French noise assessment standard is based on the concept of 'homogeneous classes' which describe the sound environment (vb. morning rush hours, night, …) at a location. These homogenous classes are to be determined by the noise expert and have to meet a number of criteria. In each of these homogeneous classes the background noise is to be assessed, and subsequently the noise limit for that class can be derived.

In order to determine the background noise, the main parameters, e.g. sound pressure level, wind speed and wind direction, are to be obtained. Measurements can be carried out indoors and outdoors, with or without wind turbine activity. Analyses are to be performed in dB(A) and per frequency band.

Immission measurements near dwellings

In this method, the noise level is determined by subtracting the total noise level in LA50 with turbines in operation, with the residual noise level (without wind turbine operation). This so called '*émergence*' is determined with the following formula:

Emergence = $LA50_{ambiant} – LA50_{résiduel}$ in dB(A)
With: $LA50_{ambiant}$ = the total noise level with wind turbine in operation
$LA50_{résiduel}$ = the residual noise level without wind turbines in operation

If the total noise with wind turbines in operation is lower than 35 dB(A), the wind turbines are in accordance with the noise regulations. If the total noise is higher than 35 dB(A), the *'émergence'* may not be higher than 5 dB(A) during the day and 3 dB(A) during the night.

Noise limits within a wind farm

In a specific area within or near a wind farm, other noise standards need to be met. These noise levels are to be measured in or at a short distance of the wind farm. The area in which these measurements need to be performed, is determined as the smallest possible polygon of the circles around every wind turbine with a radius of R = 1,2 x (hub height + ½ rotor diameter), as displayed in Figure 1.

The noise may not exceed the following limits in this area:

- Day: 70 dB(A) during the daytime (7h-22h)
- Night: 60 dB(A) during the night time (22h-7h)

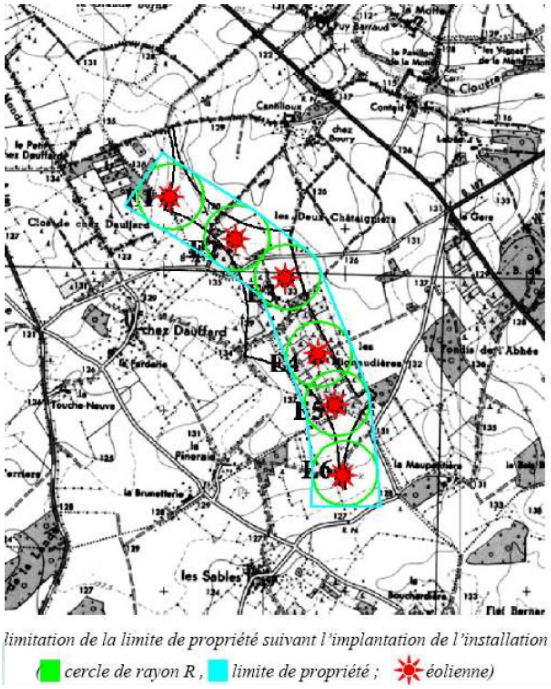
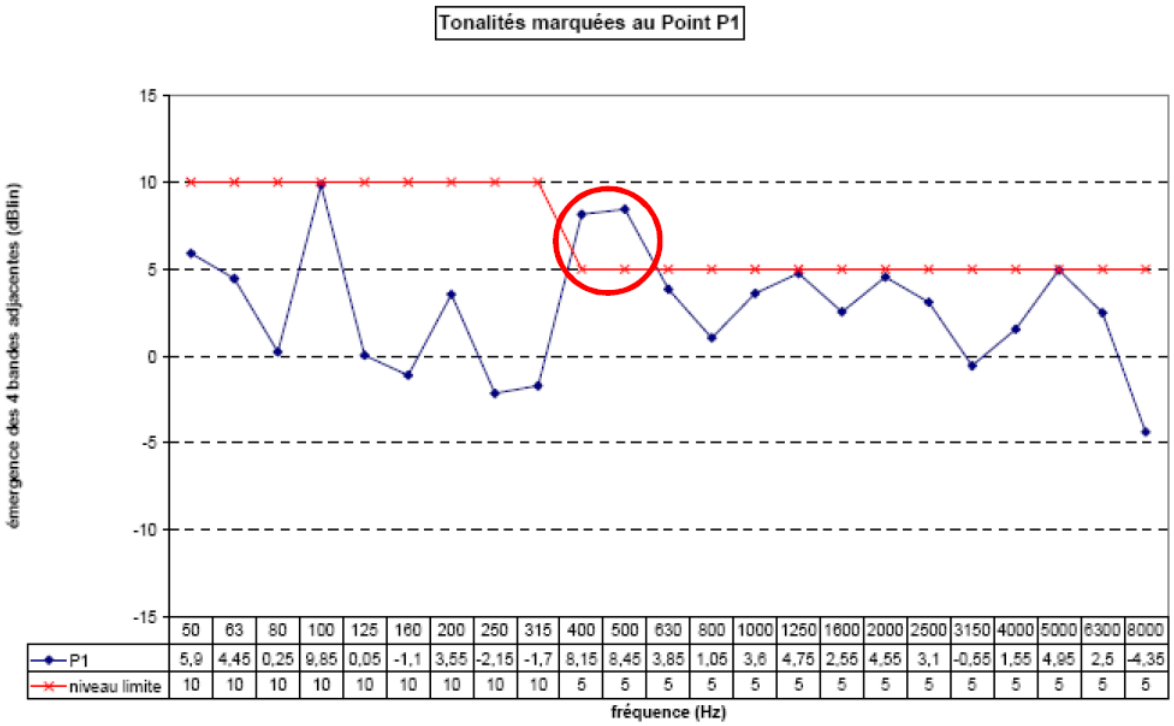


Figure 1: Illustration of the polygon in which the noise limits of 70 dB(A) in daytime and 60 dB(A) in nighttime within the wind farm are to be met (GANTHA 2012)

Tonality

Tonality is defined as the presence of a specific, clearly identifiable tone in the sound spectrum, which can cause (additional) annoyance. Determining tonality proves the emission of a certain noise frequency. The noise limits are defined in 1/3 octave bands or the 4 adjacent bands (Figure 2):

- 63 Hz to 315 Hz: 10 dB
- 400 Hz to 1250 Hz: 5 dB
- 1600 Hz to 6,3 kHz: 5 dB



	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
P1	5,9	4,45	0,25	9,85	0,05	-1,1	3,55	-2,15	-1,7	8,15	8,45	3,85	1,05	3,6	4,75	2,55	4,55	3,1	-0,55	1,55	4,95	2,5	-4,35
niveau limite	10	10	10	10	10	10	10	10	10	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Figure 2: illustration of tonality with NFS 31-114 (July 2011) (GANTHA 2012)

Methodology

A noise assessment report always needs to contain the following elements:

- a map of the site, with indication of the location of the measuring equipment and points;
- the measuring techniques;
- description of the measurement conditions;
- description of the noise environment on every measurement location, and identification of the noise sources;
- justification of the chosen homogeneous classes;
- a scatterplot for every homogeneous class, with descriptors and noise indicators in relation to the wind speed;
- a table of the values for all calculated noise indicators and their uncertainties.

At the start of the measuring campaign, the most exposed dwellings are selected by the sound expert, and both wind speed and noise level are measured at these points for more than 7 subsequent days. Subsequently, the future noise impact is calculated on the environment according to ISO standard 9613. When the noise limits will be exceeded, noise-abatement actions are to be proposed, such as the reduction of the sound power level of the wind turbines (‘*bridage’*). In every residential area, measurement locations are chosen as illustrated in Figure 3.

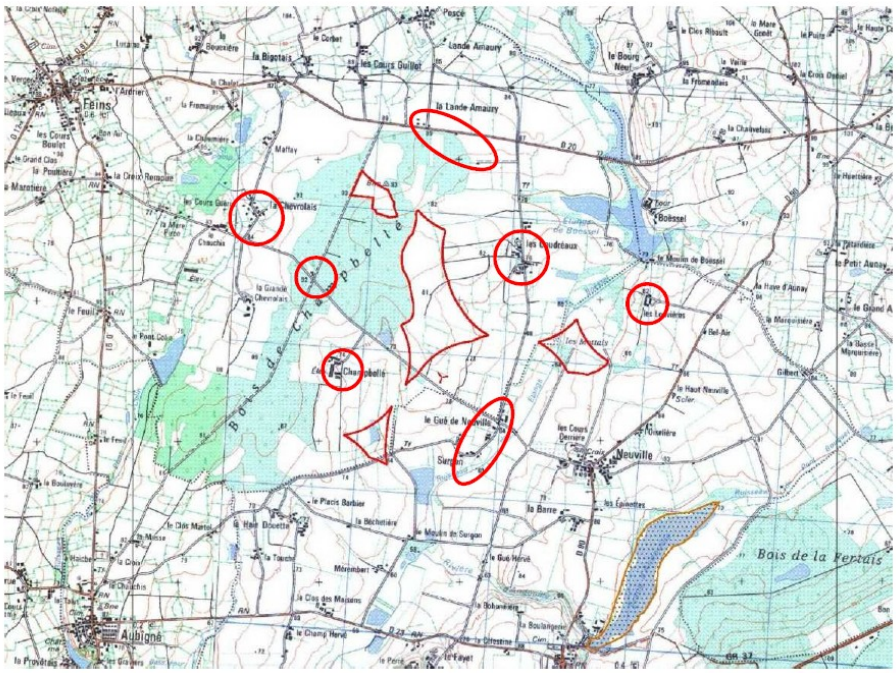


Figure 3: illustration of selection of residential areas and measurement locations with NFS 31-114 (July 2011) (GANTHA 2012)

Statistics and data processing

Noise is measured near dwellings, with the statistical parameter $LA50_{10min}$. It is important to illustrate how measurements are done (data processing). The French noise assessment method contains a detailed statistical processing of the data. This is illustrated with the following example.

First, a scatter plot with wind speed (y-axis) and noise level (x-axis) is to be given. The noise level with wind turbines in operation (*bruit ambiant*) and the noise levels without wind turbines in operation (*bruit résiduel*) are illustrated (figure 4):

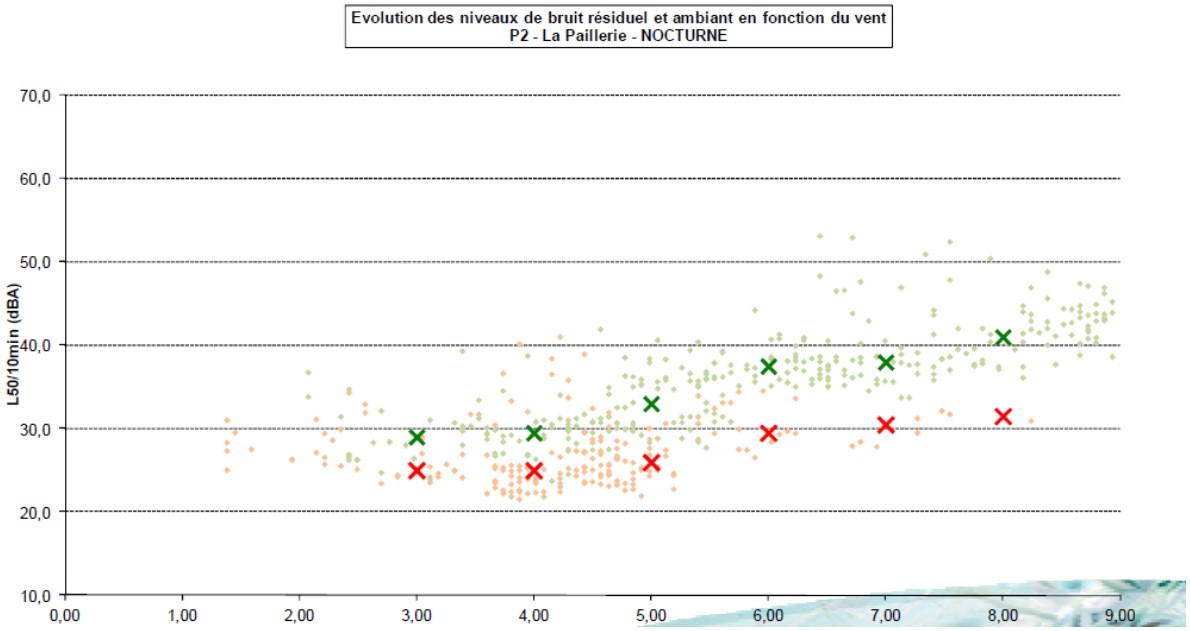


Figure 4: illustration of the total noise levels with wind turbines in operation (bruit ambient, in green) and the residual noise levels without wind turbines in operation (bruit résiduel, in red) with NFS 31-114 (July 2011) (GANTHA 2012)

For each measurement point and for each homogeneous class, the non representative noise levels (*crénaux hors norme*) are to be removed, such as:

- periods of rain
- values with a wind speed higher than 5 m/s at the microphone
- certain events (for example, isolated events with a high intensity)

This is illustrated in figure 5 and 6.

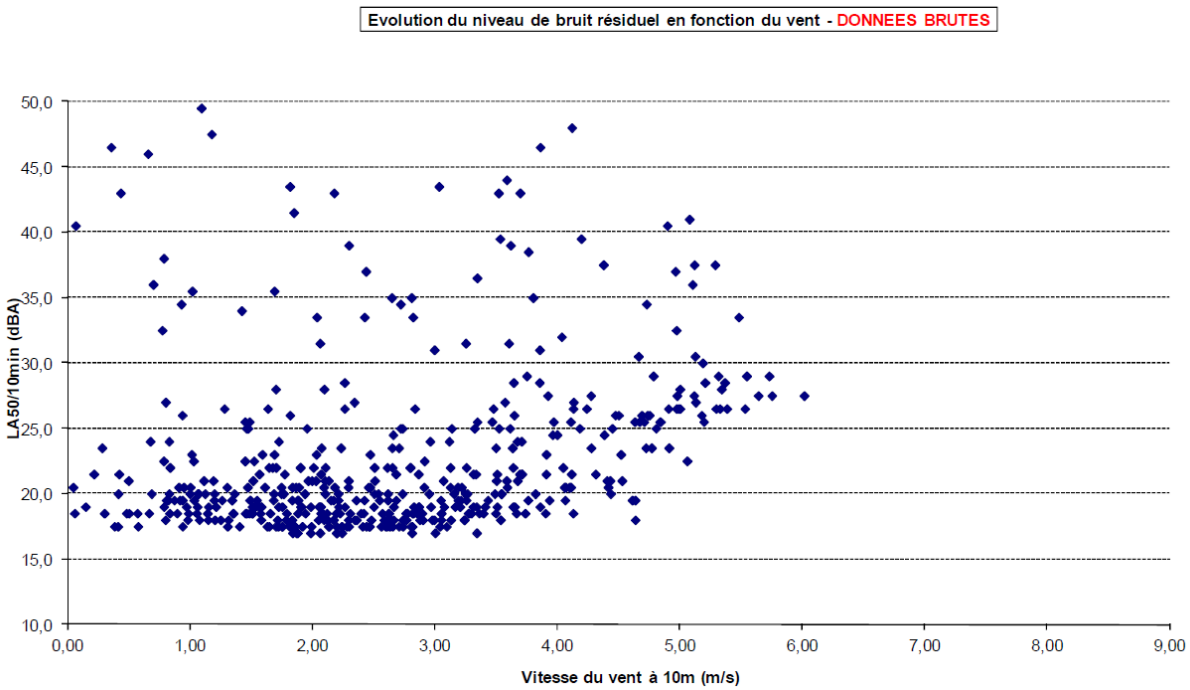


Figure 5: raw data of noise levels without wind turbines in operation (bruit résiduel) *(GANTHA 2012)*

The removal of non representative noise levels (*crénaux hors norme*) results in a filtered dataset, as shown in Figure 6

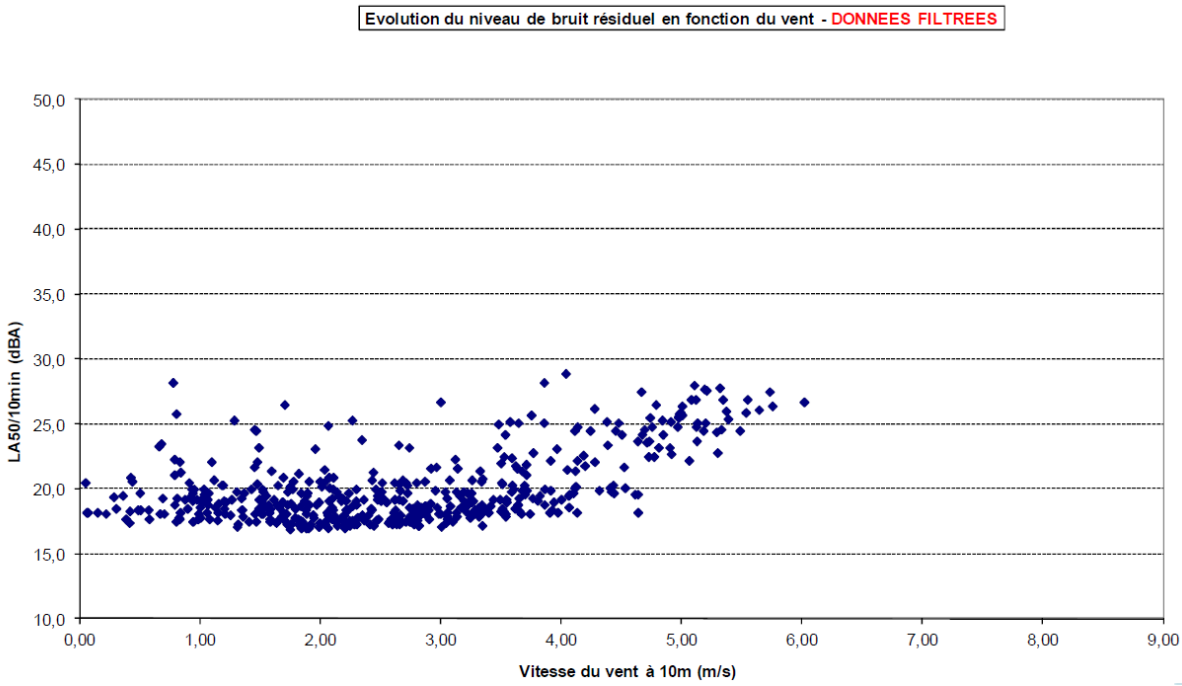


Figure 6: filtered data of noise levels without wind turbines in operation (bruit résiduel) *(GANTHA 2012)*

After this operation, the characteristic sound levels near the dwelling are determined as following (figure 7):

- The wind class is defined as the interval n ± 0,5 m/s (with n as a integer varying from 1 to 5);
- In every wind class, the median $LA50_{10min}$ is calculated
- For wind speeds higher than >5 m/s (measurement data may not be used), these values are extrapolated

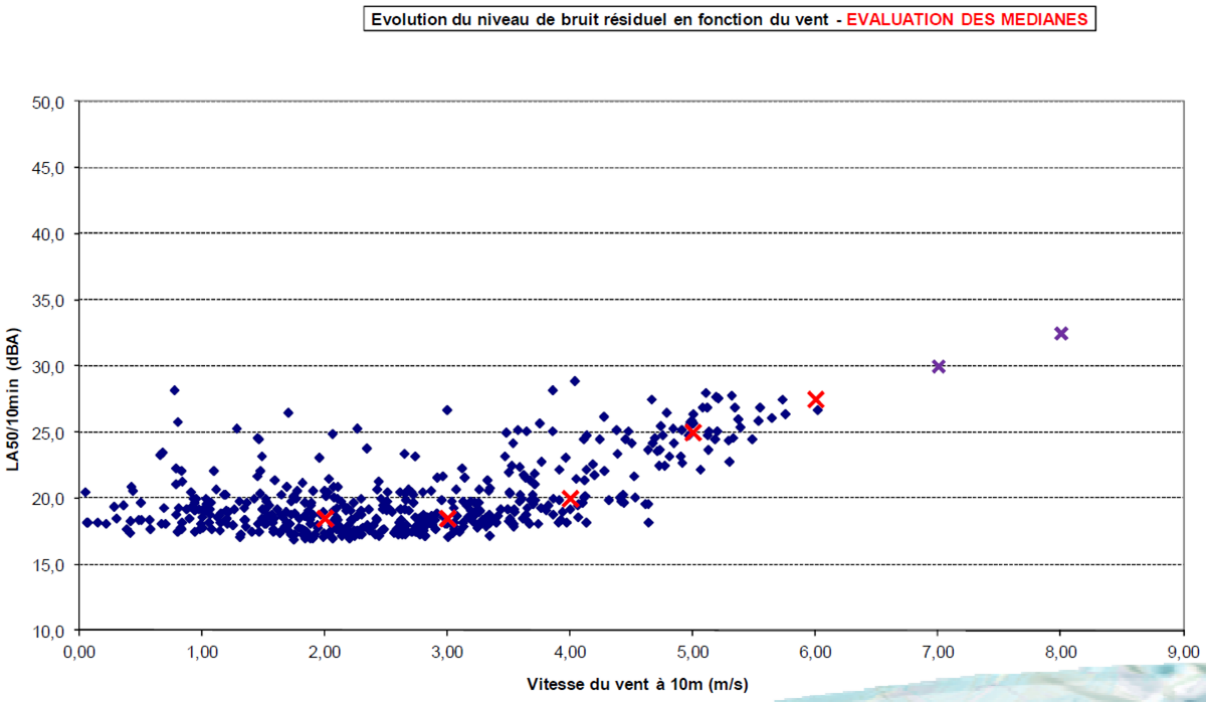


Figure 7: determination of medians for each wind class (GANTHA 2012)

After further processing (e.g. error calculation), for every homogeneous class, and for every wind class, the noise levels are checked with the noise limits (*'seuils réglementaires'*).

The French NF S 31-114 guidelines specify in detail the measurement conditions and the required data processing.

Wind induced noise

The French standard states that when using a wind screen of 10 cm, the wind-induced noise is acceptable up to a wind speed of 5 m/s. The sound expert has to motivate that this condition (maximum wind speed of 5 m/s) is not violated, either by performing wind speed measurements on site, or by performing a study of the air flow on the site.

Measurement of the wind speed must be synchronised with the sonometer.

Noise measurements

The French standard states that the locations of the outdoor measurement are to be chosen in the free field in the environment of dwellings (for example in gardens or terraces) or at 2 m distance of the wall of the dwelling. Indoor measurements are also possible, and must meet the criteria stated in NF 31-010.

Interfering noise

The standard also states that non-representative, interfering noise must be removed from the analysis, either by observations on site, or by processing the audio-recordings after the measurements.

According to the standard, the use of the statistical index LA50 allows for excluding acoustical events of short duration (less than half of the duration of the interval) and of high intensity. Otherwise, the NF S 31-114 states that these events could disproportionately raise the sound level. The use of this statistical parameter also limits the need of intervention by the operator as much as possible and allows for a consistent processing of the measurements.

Measuring uncertainty

The French uncertainty calculation consists of correction factors for calibration, directivity, pressure and humidity, indirect measurement uncertainties, and others.

The NF S 31-114 differentiates two types of uncertainties. The noise indicator for a homogenous class has an uncertainty (type A) due to the distribution of the sample (*distribution d'échantillonnage*), and also an uncertainty (type B) due to the measurement of the acoustical descriptor itself.

In order to compare the results with the noise limit values (*seuils*), the total noise level with wind turbines in operation (*bruit ambiant*) and the difference with the residual noise level without wind turbines in operation (*émergence*) needs to be subtracted with their respective uncertainty and adjustment factors.

2.2.5 Evaluation

The preliminary French noise assessment method is on one hand very detailed (for example concerning error calculation), and on the other hand leaves certain defining aspects to professional judgment of the sound expert (for example determining which homogeneous classes are to be used).

On certain aspects covered by this preliminary standard, such as dealing with wind induced noise in the microphone, there seems to be no consensus yet at the international level, as illustrated by different papers at the Wind Turbine Noise 2013 (Hanssen 2013; Kamiakito 2013). This indicates that this is a complex technical matter, which might require further research.

2.3 Netherlands

2.3.1 Overview

On the 14th of October 2010, the Dutch government approved the new environmental legislation for wind turbines based (Dutch Government 2010a), which entered into force the 1st of January 2011. At the same time, the Dutch government approved and published the new measuring and rating method for wind turbine noise, more precisely the '*Reken- en meetvoorschrift windturbinegeluid'* (Dutch Government 2011).

The Dutch measuring requirements are based on the international standard IEC 61400-11 (ed. 2), a standard method for acoustic noise measurement techniques of wind turbines. It consists of measurements close to the wind turbine (at a distance of hubheight + 1/2 rotor diameter).

Immission measurements near dwellings are not considered in the Dutch legislation and measuring requirements, although an additional method was developed for carrying out swift enforcement measurements.

2.3.2 Summary of the Dutch wind turbine noise legislation (2011 – present)

With the order of 14 October 2010, the yearly averaged noise limit values of 47 dB(A) L_{den} and 41 dB(A) L_{night} of the circular were set in the Netherlands. These limitation levels apply at the facade of dwellings and other noise-sensitive buildings and at the boundary of noise-sensitive areas. The so-called 'windnormcurve', was relieved. In the new wind turbine noise framework in the Netherlands, L_{den} is being used because it should be the best indicator for annoyance and other health effects related to noise.

The Dutch government stated in the motivation of the new legislation that the new noise limit values in L_{den} and L_{night} are similar to the former limit values of the 'Activiteitenbesluit' of 50 dB(A) in daytime, 45 dB(A) in the evening and 40 dB(A) in the nighttime.

In the new legislation, it is also possible to provide more extensive, tailor-made protection when required due to extraordinary local circumstances, for example near protected quiet areas.

2.3.3 Summary of the Dutch noise measurement and calculation method

Together with the new legislation, the definitive version of the Dutch noise measurement and calculation method was published '*Bijlage 4 van Activiteitenregeling - Meet- en Rekenvoorschrift windturbines*'. This method consist of a slightly modified version of the Dutch translation of the international standards ISO 9613-2:1996 (calculation) en de IEC 61400-11:2002 'Acoustic noise measurement techniques'. This final measuring and rating method was preceded by a similar concept document, which was valid from February 2010 until January 2011 (Dutch Government 2010b).

The intention of the newly approved measurement and calculation method is to determine the noise levels in the environment of the wind turbines. It is suited for modern, high wind turbines in the first place, but it is, according to the method, also suited for all wind turbines with horizontal axis.

As mentioned, in the new noise framework in the Netherlands, L_{den} is used. The use of L_{den}, has the disadvantage that enforcement by immission measurement near dwellings is difficult, as it is a yearly averaged value. As such, specific emission measurements are required, which were approved together with the new environmental legislation.

This new measurement method is based on the widespread standard NEN-EN-IEC-61400 part 11 (2002). The main differences between the Dutch measurement method and the IEC standard are:

- The wind speed should be measured for all relevant wind speeds instead of the wind speeds from 6 up to 10 m/s, at a height of 10 m;
- The sound power level is related to the wind speed at hub height, instead of the standard height of 10 m.

2.3.4 Short description of the noise assessment method

Measurement method

The sound power level of the wind turbine is to be determined, per octave band and as a function of wind speed on hub height. Sound measurements are done downwind of the wind turbine.

Sound measurements should be made at relatively short distance of the wind turbine. To prevent wind-induced noise in the microphone and to prevent ground effects, the microphone is attached to a measurement board on the ground. This results in a doubling of the sound pressure level at every frequency and causes a 6 dB increase in sound level (Figure 8).

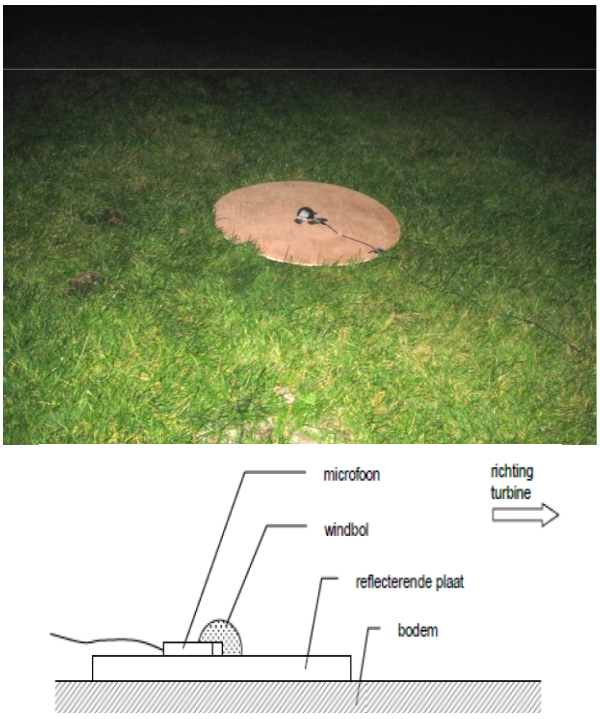


Figure 8: photo and illustration of the measurement setup (photo DGMR 2012, illustration Dutch Government 2011)

During a measurement, not only the results of the sound measurement, but also meteorological data and other operating setting, such as the electrical power production and orientation of the axis, are taken into account.

The measurement setup has one obliged reference point (P1), and five optional measuring points (cf. IEC 61400-11). The reference point P1 is located downwind of the wind turbine (Figure 9).

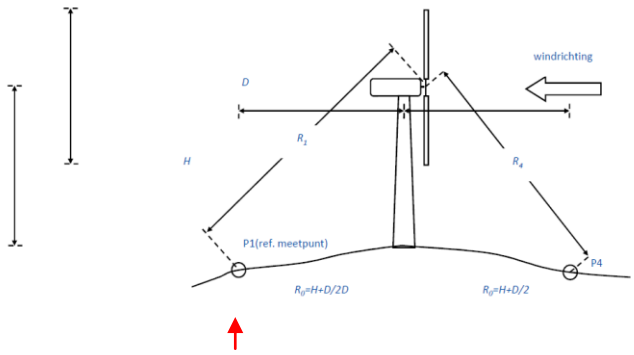


Figure 9: schematic view of measuring positions P1 (downwind) and P4

The distance between the measuring location and the wind turbine is given by the sum of the hub height and half of the rotor diameter:

$$R_0=H+D/2$$

With:

- H: vertical distance between the ground and the hub height
- D: rotor diameter

For example, for modern, large wind turbines this is a distance of about 150 m (hub height (100 m) + rotor diameter (100m)/2 = 150 m).

This reference point serves to determine the sound power level of the wind turbine. During the measurements, the rotor is to be right-angled to the wind direction at hub height. The angle of the rotor axis can vary slightly (up to ±15°) to the wind direction (Figure 10).

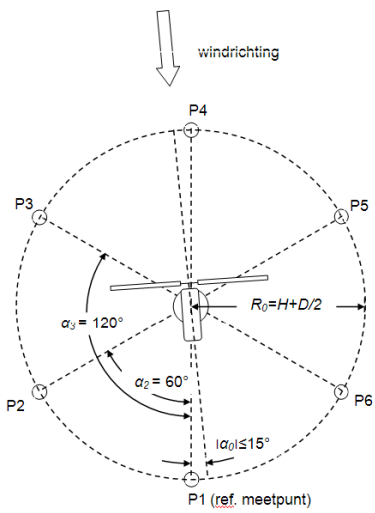


Figure 10: overhead view of the measuring positions

During the measurements, a number of criteria need to be met: 1) It is not allowed to perform measurements during fog; 2) Before and after the measurements, the instruments need to be calibrated; 3) Periods with intermittent background noise, are to be removed; 4) If there are conditions with continuous noise interference, the measurement needs to be corrected. In order to do this correction, the wind turbine needs to be turned off, and a new measurement need to take place in the same conditions (same wind speeds as with the wind turbine turned on).

Measurements of the wind speed dependent sound power level

In order to determine the wind speed dependent sound power level, it is required to measure the A-weighted octave band spectra (32,5 – 8000 Hz) for intervals with a duration of at least 1,0 minute. Measurements need to take place at wind speeds at hub heights between the cut-in wind speed (V_{ci}) up to the wind speed of 95% of the maximum power (V_{rated}).

For every integer value of wind speed V_H ± 0,5 m/s, at least three measurements need to be obtained. The full measurement consists of at least 30 measurements of minimum 1,0 minute. In order to gather sufficient data, it may be required to organize multiple sessions, although in the case of enforcement measurements, the measurement program can be shortened.

Enforcement measurements

The aim of conducting enforcement measurements is inspecting of the sound power level of the wind turbine. As extensive determination of the sound power level can be time-consuming, the Dutch Government developed a method which allows for random, faster checks of the sound power level.

The enforcement measurement deviates from the general Dutch method of the *Reken- en meetvoorschrift*, and requires 6 measurements of at least 1,0 minute for every integer value of the wind speed ± 0,5 m/s. The total A-weighted levels are considered instead of octave band levels, and a linear regression is used on the total A-weighted level. After that, the sound power level is determined for every integer value of the wind speed (Figure 11). The wind speed at hub height is supplied by the operator, which can be also checked by inspection of the rotor speed.

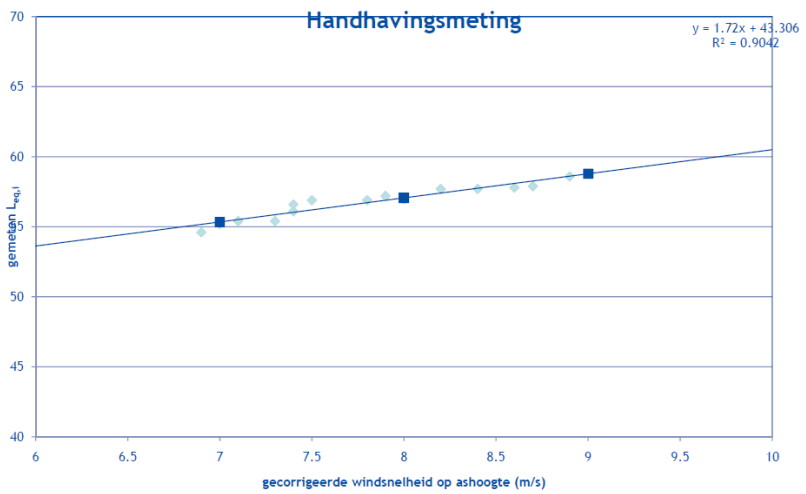


Figure 11: sound pressure level in relation to the corrected wind speed at hub height (DGMR 2012)

Measurements and noise interference

Although the Dutch method is not based directly on background noise, the method deals with interfering noises. The octave band levels for P1 are plotted with the wind speed at hub height. Subsequently, for each octave band the third grade polynomial is calculated (Figure 12).

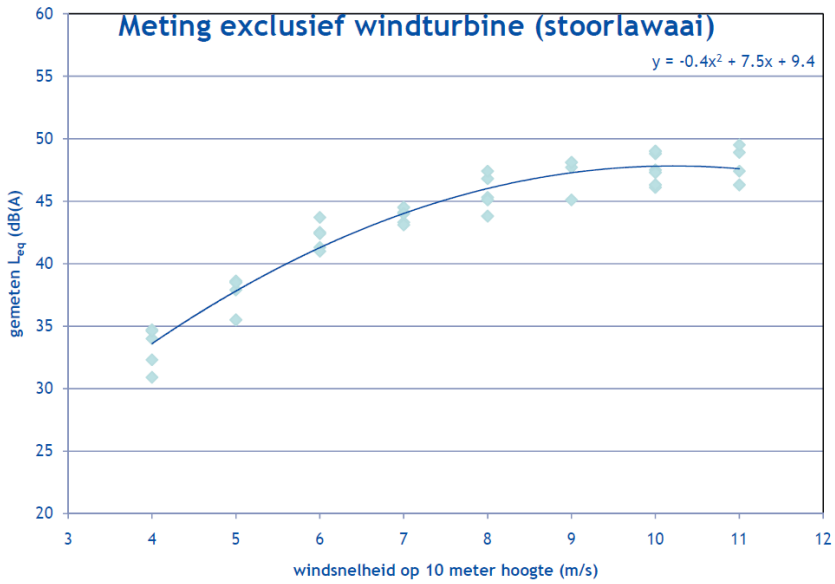


Figure 12: measurement data in conditions with interfering noise, with wind turbines turned off (DGMR 2012)

For every integer value of the wind speed at hub height (in m/s), the equivalent octave band level $L_{eq,i,j}$ is calculated, and the sound power level is derived from the following formula

$$L_{W,i,j} = L_{eq,i,j} - 6 + 10\lg\left(4\pi R_1^2\right) = L_{eq,i,j} + 5 + 20\lg R_1$$

With:

- $L_{W,i,j}$: the sound power level for each octave band i and wind speed class j
- R_1 : the distance between measuring point P1 and the center of the rotor
- j : integer value of the wind speed in m/s, going from V_{ci} (cut in wind speed) up to V_{rated} (wind speed at 95% of rated power)
- 6 : adjustment factor for the measurement board on the ground

Finally, the emission factor L_E is calculated, which represents the yearly averaged sound power level for each octave band that is emitted by the wind turbine. It incorporates the local wind speed distribution U_j (to be obtained at the Royal Dutch Metereological Institute), the wind speed dependent sound power level of the installation $L_{W,i,j}$ and an (optional) correction factor for directivity effects ΔL.

$$L_E = 10\lg\left(\sum_{j=V_{ci}}^{V_{co}} \left(\frac{U_j}{100} 10^{L_{W,i,j}/10}\right)\right) + \Delta L$$

2.3.5 Evaluation

The Dutch noise assessment and rating method is primarily focused on determining the emitted sound power level of a wind turbine, and strongly resembles the widely spread standard IEC61400-11.

Basing noise assessment methods on an international standard has the benefit of using a well-described procedure. Hence, there seem to be very few remarks from a technical point of view within the acoustical community (personal communication Dutch sound experts, 2011).

However, immission measurements near dwellings are not possible with this method, which might be a disadvantage in relation to communication to citizens. The advantage of the Dutch method, is that the method for sound power level measurements is based on an international standard (reliability), and are easier to carry out than immission measurements near dwellings. In the Dutch method, it is also possible to carry out swift enforcement measurements, which don't require as much time and data as an extensive measurement.

2.4 UK

2.4.1 Overview

Since 1996, specific environmental regulations for wind turbines exist in the United Kingdom. Together with these environmental regulations, a method for 'The Assessment and Rating of Noise from Wind Farms' (ETSU-R-97) was introduced, which mainly serves to determine the noise level when the siting wind turbines.

Commissioned by the British Government (DECC), the company Hayes McKenzie performed an analysis and formulated recommendations on the implementation of the ETSU-R-97 (Hayes McKenzie 2011). Subsequently, the British Government commissioned the Institute of Acoustics to incorporate the recommendations of the Hayes McKenzie report in a Good Practice Guide, which was published in May 2013, after two reviews and an public consultation of 10 weeks (Institute of Acoustics 2013). This Good Practice Guide supplements the ETSU-R-97 with guidelines.

2.4.2 Environmental regulation for wind turbines in the UK

In the United Kingdom, the ETSU-R-97 sets the regulations for wind turbines. In this DTI-guideline, the background noise measured as $LA90_{,\ 10min}$ is used. The noise of wind turbines may not be higher than the value for the background noise + 5 dB(A). Additionally, there is also a noise limit value of 43 dB(A) at night.

In rural areas, there is also a noise limit value during the daytime. The noise may not exceed a limit value of 35 to 40 dB(A), depending on the number of dwellings and the installed capacity. Noise with a tonal component is treated more stringent.

In England, Scotland, Wales and North Ireland, specific regulations exist for the siting of wind turbines on land, but for the noise aspect, they refer to ETSU-R-97.

2.4.3 Summary of the ETSU-R-97

ETSU-R-97 sets noise limits for wind turbines during night and daytime. These noise limit values are applicable up to wind speeds of 12 m/s at 10 m height. The use of a maximum wind speed is due to the complexity of measuring sound at high wind speeds, and the fact that lower wind speeds are the most critical in determining the noise limit values.

A noise assessment of a wind park should include:

- Determination of the prevailing background noise at all operational wind speeds of the wind turbines (5 m/s, 6 m/s, 7 m/s, …);

- Selection of the wind turbine type, based on the guaranteed sound power level of the manufacturer;
- A noise immission calculation, using GIS-data and wind turbine data;
- An impact analysis at all sensitive receptors.

The background noise is determined by plotting the sound pressure level (L90) and the wind speed at hub height, using a best fit curve (Figure 13).

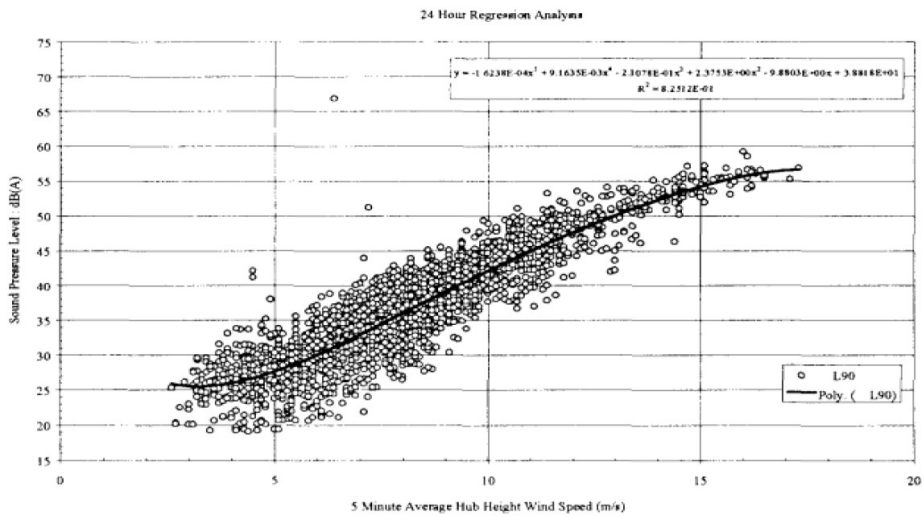


Figure 13: determination of the background noise, using a best fit curve (ICAN Acoustics 2011)

During the daytime, the noise limit is 35 to 40 dB LA90, or +5 dB above the 'quiet day-time hours prevailing background noise' (highest value is applicable). The 'quiet day-time periods' are defined as evenings from 18h00 until 23u00, Saturday afternoons from 13h00 until 18h00 and Sundays from 7h00 until 18h00. The particular limit value within the 35-40 dB LA90 range depends on the number of dwellings, the impact of the noise limit on the electricity production, and the duration of the exposure (Figure 14).

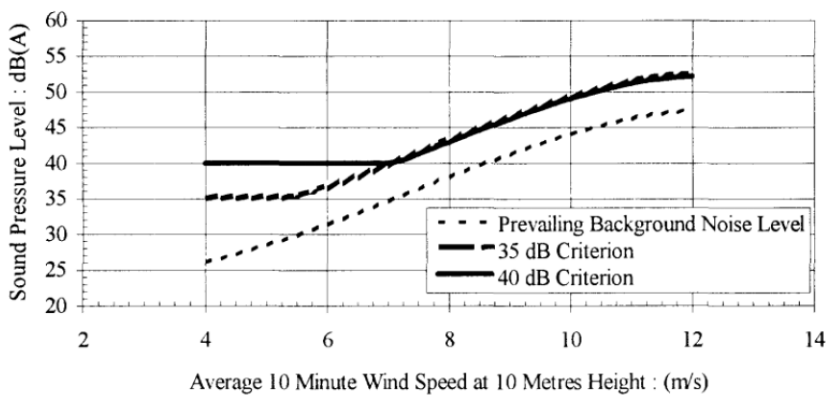


Figure 14: determination of the noise limit during the daytime (ICAN Acoustics 2011)

During the nighttime (23h00 – 7h00), the noise limit value is 43 dB LA90 or +5dB above the the 'quiet day-time hours prevailing background noise' (highest value is applicable). The noise limit of 43 dB LA90 is based on the criterion for sleep disturbance of 35 dB LAeq, with a +10 dB adjustment factor for open windows and a -2 dB adjustment factor for using LA90 instead of LAeq (Figure 15).

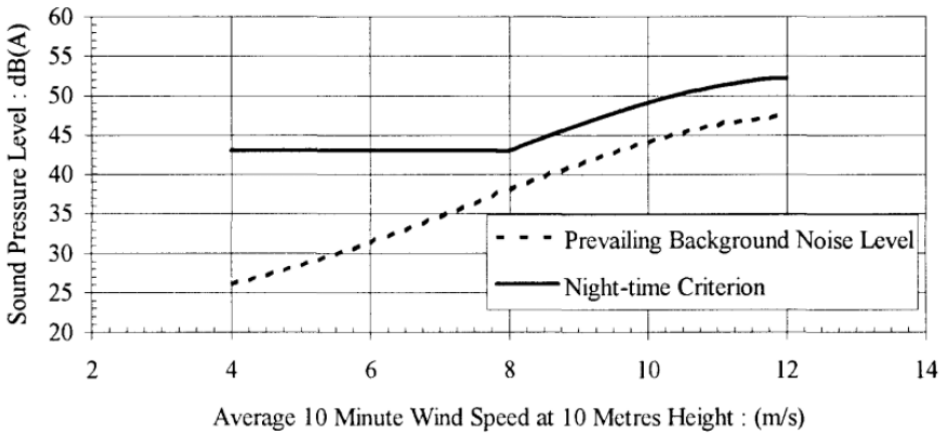


Figure 15: determination of the noise limit during the night time (ICAN Acoustics 2011)

If the persons living near the wind farm are financially involved in the project, the noise limits for daytime and night time can be raised up to 45 dB LA90 or the adjustment factor for the background noise can also be raised.

If the predicted noise levels are low at the nearest dwelling, a simplified noise limit can be used. In that case, the noise is limited to 35 dB LA90 with wind speeds up to 10 m/s at 10 m height. This ensures that no extensive background noise measurement is required.

The method states that the LA90 descriptor for wind turbines is about 1.5 to 2.5 dB lower than the measured LAeq in that period. The use of LA90 allows for making reliable measurements, without interference of other relatively loud, intermittent noises.

When a tonal component is present, ETSU-R-97 states that the noise limits are to be corrected with an adjustment factor. The level of adjustment is dependent on the audibility of the tonal component.

2.4.4 Good practice guide for ETSU-R-97

The Institute of Acoustics developed a good practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise.

This good practice guide covers all relevant aspects of noise measurements, such as determination of the background noise, wind speed measurements, and analysis of the data in order to determine the noise limits.

Some of the recommendations of this good practice guide are general in nature (e.g. engagement of all the relevant parties from an early stage is desirable) but most are detailed technical requirements.

These include recommendations for:

- noise measurement equipment: e.g. use of enhanced microphone windscreens;
- measurement location: e.g. measurements in amenity areas between 3.5 and 20 m from a dwelling;
- measurement duration: e.g. no fewer than 200 valid data points should be recorded in each of the amenity hours and night time periods, with no fewer than five valid data points in any 1 m/s wind speed bin;

- synchronising of equipment: e.g. measurement intervals for wind speed, noise level and rainfall should be synchronised to within at most one minute over the survey period;
- removal of certain types of data: e.g. the presence of noise sources which are not common should be removed from the data; removal of clear dawn chorus effects; excluding of any data directly affected by rainfall;
- data analysis: use of regression analysis (linear to fourth order), depending on the nature of the noise environment;
- ...

3.0 Evaluation

In this section, the similarities and differences in noise assessment methods for wind turbines are evaluated, as well as some remaining uncertainties.

3.1 Similarities and differences in the noise assessment and rating methods

3.1.1 Dealing with non-representative data

In the three reviewed countries, non-representative data (for example: periods of rain) are to be removed from the analysis.

In France non-representative data is to be removed either based on observations on site, or by processing audio-recording afterwards. Examples of non-representative measurements are 1) noise measurements in wind speeds higher than 5 m/s (these values cannot be used, these values need to be extrapolated), 2) extraordinary events (for example, isolated events with a high intensity), or 3) periods of rain.

In the United Kingdom, seasonal effects are to be eliminated in the dataset either by removal of atypical data during analysis of (pro-active), the choice of the measurement location. In the United Kingdom, rain is excluded from the analysis. The use of the statistical parameter LA90, implies, according to the noise assessment method, that extraordinary events are filtered out.

In the Netherlands, a difference between continuous and discontinuous interference noise is made. Periods with discontinuous interference noise are not to be included in the analysis, but periods with continuous interference noise the measurement needs to be corrected. In order to do this correction, the wind turbine needs to be turned off, and the measurement needs to be repeated in conditions with a similar wind speed. In the Netherlands, the noise assessment method also states that during periods with dense fog or rain, noise measurements are not allowed.

3.1.2 Use of a class 1 measuring equipment

In the studied countries, only class 1 microphones can be used for measurements of wind turbine noise:

- In France, class 1 microphones (NF EN 60804) is to be used, or noise measuring equipment which is able to do short Leq measurements;
- The United Kingdom states that ‘Noise measurement equipment and calibrators used on site should comply with Class 1/Type 1 of the relevant standard(s).’;
- In the Netherlands, the measurement equipment must meet the criteria for class 1 equipment (NEN-EN-IEC 61672), the octave band filters must meet the criteria of NEN-EN-IEC 61260 and the calibration equipment must meet the criteria of class 1 equipment cf. NEN-EN-IEC 60942. The specifications of the instrumentation are to be checked every two years.

3.1.3 Synchronising measurements of microphones, wind meters, …

In France, the smeasuring equipment used for determination of the wind speed is to be synchronized with the noise measurements. In the United Kingdom, measurement equipment is to be synchronized according to the recommendations of the Institute of Acoustics: *'SB11: Measurement intervals for wind speed, noise level and rainfall should be synchronised to within at most one minute over the survey period. Logging devices may use different time references (GMT or BST) and the logging protocol may apply a time marker at either the start or end of a measurement interval. Such differences must be taken into account. Synchronisation of rainfall measurements is less critical.'*

It should also be noted that especially in the third edition of the IEC61400-11 standard, synchronizing measurements between the different parts of the measuring equipment is also an important aspect.

3.1.4 Choice of the measurement location

In France, locations of the outdoor measurements are to be chosen in the free field in the environment of dwellings (for example in gardens) or at 2 m distance of the wall of the dwelling. In the UK, the Institute of Acoustics states that measurements should be made in amenity areas between 3.5 and 20 m from a dwelling. In the Netherlands, the measurement location is based on the distance from the wind turbine, i.e. at a distance of about 150 m ((hub height + ½ rotor diameter).

3.1.5 Use of wind classes

In the considered countries, sound measurements are made in function of wind speed. France and the Netherlands use discrete wind classes (for example 4 m/s ± 0,5 m/s, 5 m/s ± 0,5 m/s) for further analysis (Figure 16, 17 and 18).

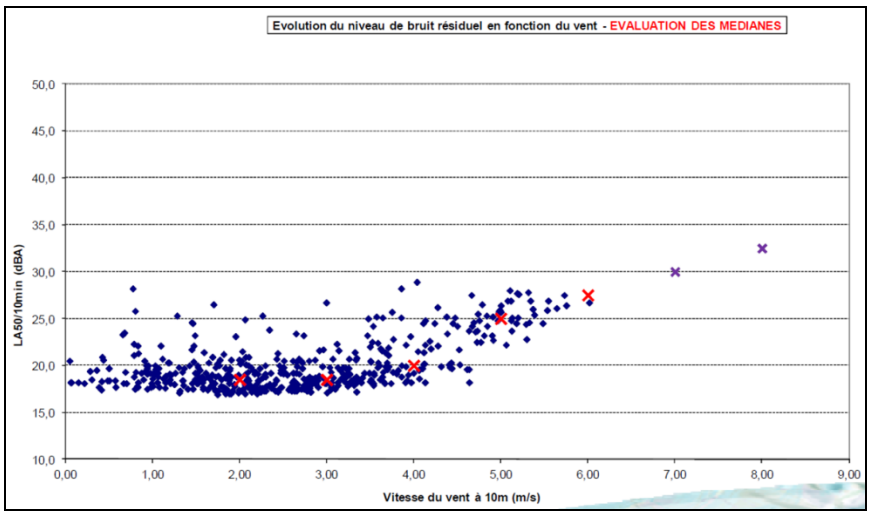


Figure 16: (France) $LA50_{10min}$ (dBA) in relation to wind speed at 10 m height (m/s)

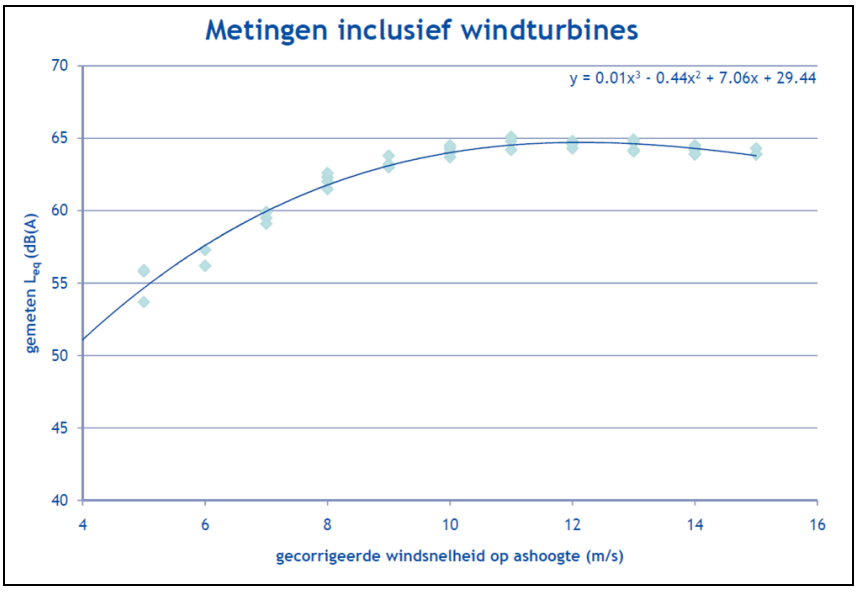


Figure 17: (The Netherlands) Leq (dBA) in relation to the corrected wind speed at hub height (m/s)

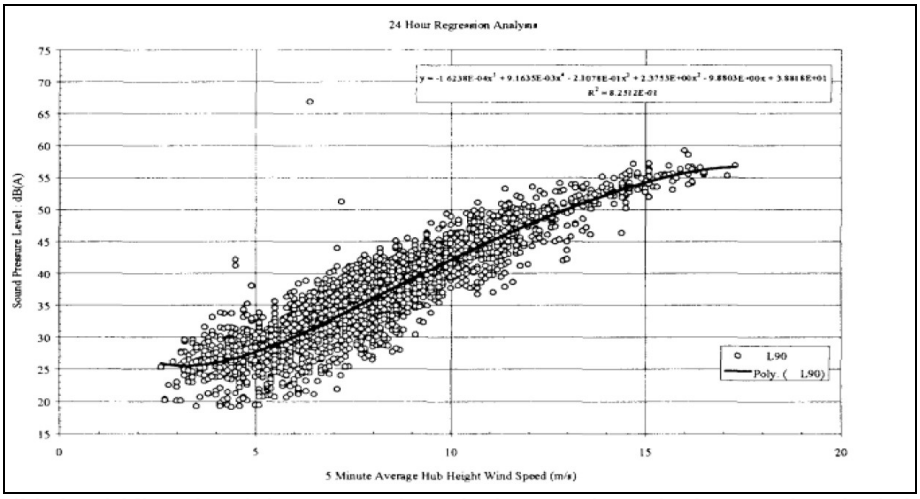


Figure 18: (United Kingdom) L90, $_{5\ min}$ in relation to the wind speed at hub height (m/s)

3.1.6 Statistical processing of the data

The noise assessment and rating procedures of the considered countries all provide rules for statistical processing of the data. In France, the median sound level is determined per wind class (vb. 5 m/s : [4,5 m/s – 5,5 m/s]). In the United Kingdom, a linear to fourth grade regression function is used for evaluation. Also the Netherlands are using regression analysis with a 3th grade polynomial if there is continuous interference noise present.

3.1.7 Measurement duration

In the United Kingdom, it is stated that at least 200 datapoints, measured as $LA90_{10min}$, should be obtained, with additional rules if the background noise is strongly dependent on the wind direction or if the data is scattered. In France however, several hundred datapoints with a minimal duration of 10 minutes are required ($LA50_{10min}$). In practice, measurement campaigns of 7 days are carried out according to an acoustical agency (Gantha 2012).

Finally, in the Netherlands, the measurement duration can be shorter, since at least 30 measurements of at least 1,0 minute are required. This is also subject to the prevailing meteorological conditions, so in order to gather sufficient data, this may take some time, and it may be required to organize multiple measurements.

3.2 Uncertainties in the noise assessment and rating methods

3.2.1 Impact of wind on the microphone

Dealing with wind induced noise in microphones is, especially in the case of wind turbines, very complex. In a French draft (draft 3 of NF S 31-113, 7 July 2011), a relatively simple equation is suggested in (formula impact in dB(A) of wind induced noise in the microphone = 0,72 * $L_{oct16Hz}$ -12 dB). At the Wind Turbine Noise Conference 2013 however, dealing with wind-induced noise was still discussed in several papers. Hansen et. al suggested wind-induced noise could be assessed by determining the coherence between two microphones in 0,1 s intervals (Hanssen 2013). Kamiakito on the other hand suggested the use of a regression function in order to deal with wind-induced noise (Kamiakito 2013). Both methods can be applicable, but none are currently incorporated in the noise assessment and rating procedures.

There is consensus, however, on the use of wind screens on microphones. In France, the use of a wind screen is compulsory for wind speeds up to 5 m/s. Additionally, the sound expert needs to prove that this condition of 5 m/s was not exceeded, either by measuring the wind speed on site, or by performing a study of the air flows. In the United Kingdom, enhanced microphone windscreens must be used must be used with a diameter of at least 100 mm, otherwise these screens are not able to provide sufficient reduction of wind noise according to the noise assessment method. The use of wind screens (‘halve windbol’) is also obliged in the noise assessment procedure in The Netherlands, but no minimum diameter is defined. This can also be explained that by using a microphone at a flat surface (cfr. IEC 61400-11), the impact of wind-induced noise on the measurements is smaller.

3.2.2 Dealing with uncertainty

In France, the noise assessment method provides a very detailed methodology with respect to uncertainty calculation. The method consist of correction factors for calibration, directivity, pressure and humidity, indirect measurement uncertainties, Type A and Type B factors, and others factors.
No such detailed methodology concerning dealing with uncertainty is provided in the noise assessment methods of the other studied countries in this evaluation.

3.3 Overview of the development of noise assessment methods

In the following table (table 1), an overview of the development of the noise assessment and rating procedures in France, the Netherlands and the United Kingdom is shown

Table 1: overview development of the noise assessment and rating procedures in France, the Netherlands and the United Kingdom

France	Norme française NF 31-114 (Juli 2011)	Draft available?	✓ (July 2011)
		Final version available?	March 2016
Netherlands	Meet- en rekenvoorschrift windturbinegeluid (Januari 2011).	Draft available?	✓ (Feb. 2010)
		Final version available?	✓ (Jan. 2011)
		Final version accepted by the acoustical community	✓ (pers. comm. Okt. 2011)
United Kingdom	ETSU-R-97	Draft available?	✓
		Final version available?	✓ (Sep. 1996)
		Final version accepted by the acoustical community?	April 2011 – report Hayes McKenzie ✓ May 2013 – good practice guide Institute of Acoustics

4.0 Conclusions

Due to historical differences in industrial noise policy, every country has developed its own approach in dealing with wind turbine noise, both for noise legislation and for the noise rating and assessment method. Currently, no international standard for immission measurements near dwellings is available.

Developing a method for noise assessment near dwellings has proven to be technically complex, but possible. In the United Kingdom, two reviews were carried out in order to develop guidelines on how to deal with wind turbine noise measurement. In France, a preliminary method is valid until the final version of the method is published. In the Netherlands, a draft proposal based on IEC61400-11 (ed. 2) was finalized in a relatively short time, but the legislation does not require immission measurements near dwellings, which reduces some technical complexities.

Comparison international noise assessment methods show both differences and similarities. There are differences in the measured parameters ($LA50_{10min}$, $LA90_{10\ min}$,$LAeq_{1min}$), in measurement duration, among other factors. But there are also a lot of similarities, such as the removal of certain types of non-representative data (e.g. rain), the use of class 1 microphones, the requirement to synchronize equipment, the use of wind classes and regression analysis for data processing, and other similarities. Additionally, this analysis indicates there might be still some technical uncertainties left to be dealt with, for example dealing with wind-induced noise, which can be dealt with further research. This knowledge can be useful in the future development or refinement of noise assessment and rating procedures.

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