Differences in noise regulations for wind turbines in four European countries

Edwin Nieuwenhuizen
M+P, Aalsmeer, The Netherlands

Michael Köhl
Müller-BBM GmbH, Gelsenkirchen, Germany

Summary
In Europe, each country has taken its own, individual approach for regulating noise generated by wind turbines. In order to make the practical significance of those differences clear, it is insufficient to simply compare noise limits. It is also necessary to consider the calculation methodology mandated by the countries. In this paper the most important features of noise regulations for wind turbines in Denmark, the Netherlands, Germany and Belgium, are discussed. It is shown that countries use different sound power levels for the same turbine within the noise calculations. Also, dissimilar formulas for ground attenuation are used. Additionally, some countries not only enforce noise limits but distance rules as well. Two sample calculations clarify that the Dutch regulations are the least strict of the four countries presented.

PACS no. 43.50.Sr

1. Introduction

Regulations for wind turbine noise have been amended recently in most European Union member states. The amendments stem from a requirement for greater clarity from operators, governments, as well as those located in surrounding areas of the sites. Wind turbine noise has a special character that is highly dependent on weather conditions, and it can affect people differently. How this could be dealt with was often unclear. In a number of member states, this resulted in legal uncertainty and stagnation of wind energy projects. This stagnation prevented the plans of those countries to make a major part of their energy renewable. The regulatory changes should provide a boost for wind projects.
The standards IEC-61400-11 Ed. 2 (2002) and Ed. 3 (2012) provide measurement procedures aimed at characterising the noise emissions of a wind turbine. Results of emission measurements that conform to this standard are being accepted by most countries worldwide. Contrastingly, the requirements concerning the determination and assessment of noise immission levels have not been harmonised. In drafting the new wind turbine noise regulations, countries have opted to take their own, completely different approach.
In this paper, the regulations for wind turbines in four Western European countries, Denmark, the Netherlands, Germany and Belgium, will be compared. These countries consider wind energy to be an important contributor to achieving targets for renewable energy. The comparison focuses on the planning phase of wind park projects. What are the applicable noise limits and what calculation methodology will be used for demonstrating compliance with those limits? The combination of these factors determines the distance that should be maintained with respect to the properties of third parties. In some countries, distance standards will also need to be respected as well as the noise standards.
In the following sections, the regulations will first be treated generally, and then for each specific country. Then, two scenarios will be calculated in order to be able to demonstrate the differences.

2. Calculation methodology

In the case of industrial noise, the level at an assessment location is normally calculated as follows:

$$L_{pA} = L_{WA} + K - A - C_{met} \quad (1)$$

L_{pA}	eq. A-weighted SPL at the receiver
L_{WA}	A-weighted sound power of the source
K	penalty for tonal or impulse noise
A	attenuation that occurs during propagation from source to receiver
C_{met}	meteorological correction

The calculation can be carried out directly as the total A-weighted level, or first in 1/1 or 1/3 octaves, which will then be summed up logarithmically.
A wind turbine will be modelled as a point source with a height that is equal to the hub height. Some countries have their own rules for the determination of a wind turbine's noise level L_{WA}. These rules are closely related to the international standard and in practice, the (same) manufacturer data will almost always be used. These are laid down in the IEC-61400-11, Ed. 2 (2002) and Ed. 3 (2012) standard. The operational conditions of the wind turbine take preference and vary by country.
The term K is an additional weighting to the noise level that must be added if the noise has a tonal or impulsive character. Although this is dealt with in different ways, application of the guidelines rarely imposes this weighting. Therefore, the K factor will not be included here.
The term A is made up of different effects that influence the transmission of sound from the source to the receiver. This transmission attenuation occurs under favorable meteorological conditions, including downwind. For wind turbines the attenuation consists of:

$$A = A_{div} + A_{atm} + A_{gr} \quad (2)$$

A_{div} attenuation due to geometrical divergence
A_{atm} attenuation due to atmospheric absorption
A_{gr} attenuation due to the ground effect

The term C_{met} is a correction for meteorological conditions that take into account the fact that favourable transmission conditions do not always apply. Due to the large source height of wind turbines, this term is almost negligible. Hence C_{met} will not be considered in this paper.

3. Denmark

The Danish noise regulations for wind turbines is contained in Statutory Order No. 1284 [1]. On 1 January 2012, the regulations were expanded with rules for the calculation and assessment of low-frequency (LF) noise. Since then, the Danish system has been adopted by researchers in other countries due to a lack of clear national rules for LF noise.
The Danish limits for total noise apply at a wind speed of 6 and 8 m/s. These wind speeds are based on a height of 10 m, which is the reference height according to the IEC standard. For a wind speed of 8 m/s, the permitted values are 2 dB greater than those at 6 m/s. The idea behind this is that wind turbines produce more noise at higher wind speeds, but natural wind noise also increases. Due to masking effects, the widening of the standard at 8 m/s would normally not cause more nuisance. Which of the two wind speeds is relevant for the assessment depends on the characteristics of the wind turbine and the hub height.
Denmark has separate noise limits for homes in rural areas and noise-sensitive areas (including residential areas). The limit values are summarised in table 1.

Table I. noise limits in Denmark.

area	v_{10}=6 m/s	v_{10}=8 m/s
open countryside	42 dB(A)	44 dB(A)
noise sensitive land use	37 dB(A)	39 dB(A)

Annex 1 of the Order contains the noise propagation model mandated by the government. The attenuation factor for air absorption is to be calculated as 1/1 or 1/3 octave, but the ground attenuation is independent of frequency. The value is -1.5 dB for onshore turbines and -3.0 dB for offshore turbines. The Danish Order states that a margin of safety can be applied to the measured noise level of the turbine. However, in Danish environmental impact studies it is not common practice to use an additional weighting.
The limits for LF noise also apply for both wind speeds of 6 and 8 m/s. The indoor noise levels in neighboring homes will be calculated in 1/3 octave bands between 10 and 160 Hz. In any of those 1/3 octave bands the calculated level may not exceed 20 dB(A). The calculations are carried out with a similar transmission model as that prescribed for calculation of the total noise. However, the ground attenuation of LF noise differs for each 1/3 octave band and varies between -6 and 0 dB. The difference between indoor and outdoor levels will be calculated by subtracting a fixed value. This value is based on measurements of typical Danish homes.
Experience with LF noise rules show that the 20 dB(A) contours for low-frequency noise only fall outside the contour of the limit for the total noise in exceptional cases [2]. The LF rule does not, therefore, act as a limiting factor for the placement of wind turbines in Denmark.
In addition to noise standards, Denmark also has a distance standard for wind turbines. The minimum

distance to neighbouring homes is four times the total height of the turbine. The total height is equal to the hub height plus the radius of the rotor.

4. The Netherlands

On 1 January 2011, new standards for wind turbines were included in the Activities Decree, which contains general rules for businesses [3]. The special feature of the standard is that the noise from wind turbines is evaluated by the noise indicator L_{den}. This is based on the annual average noise emission, which is calculated by the local wind conditions.
In the Netherlands, no distinction is made between different area types. For every noise-sensitive location, the same standard value applies, namely 47 dB L_{den}. In addition to L_{den}, a night limit value, 41 dB L_{night}, was introduced. However, this limit brings no extra restriction. The Dutch calculating scheme is attached as an annex to a Ministerial Regulation [4]. Within this annex is a description of how the emission term will be calculated from the wind speed-dependent noise level of the turbine and the local meteorological statistics. For this purpose, the emission data of the wind turbine must be used on all common wind speeds (from circa 3 to circa 25 m/s).
The wind information is contained in frequency tables. These tables provide information about how often a certain wind speed occurs at a certain height. This data, broken down for the day, evening and night period, has been compiled by the Royal Dutch Meteorological Institute (KNMI) for the most common turbine heights using long-term wind statistics and are available online [5]. An example of the wind distribution in Netherlands is provided in Figure 1.

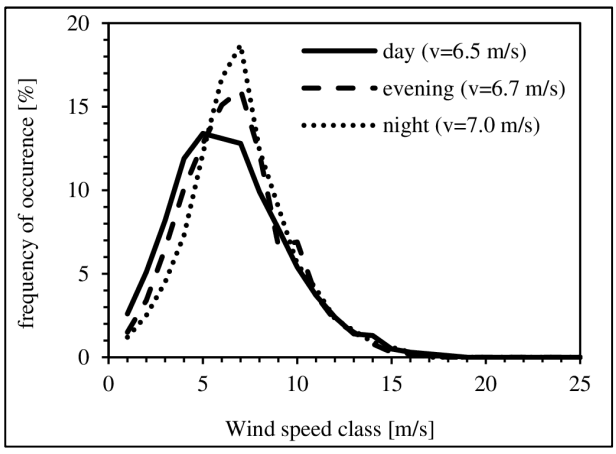

Figure 1. wind speed distribution at lat 52.6°, lon 6.7°

The result of the Dutch methodology is that the emission term for each location is different. At coastal locations, the annual average wind speed is about 2 m/s higher than inland locations. The calculated noise at a certain distance from a wind turbine at a coastal location is, therefore, about 2 dB higher than one further inland. Usually, the annual average sound emission is 4 dB below the maximum noise emission of a wind turbine.
The transmission terms of the noise calculation model are equal to those used for other industrial sources in The Netherlands. The methodology is very similar to the ISO-9613-2:1996 standard, with the exception of the ground attenuation. Porous ground lead the Dutch model to the same results as ISO-9613-2:1996. For acoustically hard surfaces, the ground attenuation according to the Dutch model is -2 dB compared to -3 dB for the ISO standard.
In the Netherlands, no account is taken of uncertainties of measurement data and the calculation method.

5. Germany

In Germany, the provisions described in the Sixth General Administrative Provision to the Federal Immission Control Act (TA Lärm) [6] are applicable to wind turbines. These administrative regulations date back to 1998 and do not contain any standards that are specifically focused on wind turbines. This means that wind turbines get the same treatment as other technical installations. The Technical Directive states that, at night, noise in pure residential areas should not exceed 35 dB(A). For villages and mixed areas, the target is 45 dB(A), see also Table II. The German situation is special, because the noise limits apply to the cumulative noise of all the business activities together. This means that there is less room within which to make noise if other nearby companies cause noise.
For the calculation of the transmission terms, the Technical Directive requires using the ISO-9613-2:1996 standard. The federal states are given the freedom to set further specific requirements. This applies especially to calculation of the ground effect and the way to deal with uncertainties. Most federal states couple these topics to the Directive of the Nordrhein-Westfalen [7].
In Germany, it is recognised that high sources such as wind turbines fall outside the scope of ISO-9613-2:1996. Using the regular – frequency-

dependent- ground attenuation from the ISO standard would lead to an underestimate, especially in porous ground. Therefore, federal states order that ground attenuation shall be calculated according to the alternative method of the ISO standard. This implies that the attenuation is independent of frequency and type of ground. The Technical Directive states that access must be provided in the quality of calculation. Included herein are uncertainties in determining the sound power, differences between wind turbines of the same series and the uncertainties of the transmission model. In most federal states, the upper limit of the 90% confidence interval of all uncertainties related to the rating level must be below the limit value. In practice, the sound power level is increased by about 2 dB.

Table II. selection of noise limits in Germany

area	*limit at night*
heartland, villages, mixed areas	45 dB(A)
gen. resid. & small urban areas	40 dB(A)
purely residential areas	35 dB(A)

The German federal states provide recommendations for minimum distances between wind turbines and housing. Many German state governments recommend that turbines should be located 750 to 1000 m away from residential areas. For solitary homes in rural areas, it is possible for there to be no restrictions at all. Usually, the recommended distance is greater than 400 metres.

6. Belgium

The protection of the environment is delegated to regional governments in Belgium. Flanders and Wallonia have totally different regulations for wind turbines.

6.1. Flanders

Since the beginning of 2012, new environmental conditions have been in place for wind turbines in Flanders. The conditions are stated in the VLAREM regulations [8], [9], [10]. VLAREM has a extensive differentiation of noise standards for each destination area. There are standards for the noise of wind turbines in 12 different destination areas. During the night, the standard is 39 dB(A) for residential areas and 4 dB higher in rural areas (Table III). VLAREM states that the noise made by wind turbines should be lower than the limit values that apply to the type of area. But it is also possible to account for ambient noise. If background noise (L_{A95}) is greater than the limit value, the true value of the background noise applies. In that case, a setback distance of at least three times the rotor diameter must be maintained.

Table III. selection of noise limits in Flanders

area	*limit at night*
residential areas	39 dB(A)
agricultural areas	43 dB(A)

In Flanders, the calculations are based on the noise level at 95% of wind turbine's rated power. A standard tolerance of 1 dB on the accuracy of the noise level will be permitted. If the tolerance is larger than that, it will be added to the noise level, reduced by 1 dB.
The transmission calculations will be carried out in accordance with ISO 9613-2:1996. Annex IV of VLAREM provides various modelling rules that must be met. The calculations will be carried out in octaves, and preferably in 1/3 octave. The ground effect must be calculated using the regular, frequency-dependent formulas in the ISO standard. In an agricultural environment, the ground will be considered as 80% porous soil.

6.2. Wallonia

At the beginning of 2014, the Walloon Government reached an agreement on sector-specific conditions for wind turbines. The standards are contained in the Decree dated 13 February 2014 [11]. The standard distinguishes between summer and winter, which is unusual when compared to other countries.
Just like Flanders, Wallonia differentiates noise standards by area destination, although less extensively. However, there is no possibility to broaden the standards based on L_{A95} measurements. For the night period, the limit is 43 dB(A) for residential and rural areas, see Table III. In summer conditions, the standard is 3 dB stricter. The summer rule does not apply in agricultural areas. The lower limit values must be respected if the temperature exceeds 16°C at 22:00. The idea behind the scheme is that during the summer, residents are inclined to open their windows. The lower limit would ensure an indoor noise level of 30 dB(A), even with open windows.

Table IV: selection of noise limits in Wallonia

area	*limit at night – summer*	*limit at night – not summer*
residential areas	40 dB(A)	43 dB(A)
rural areas	40 dB(A)	43 dB(A)
agricultural areas	43 dB(A)	43 dB(A)

Wallonia has the assessment variable $L_{Ar,part,1h}$. Unlike other countries looked at here, the assessment of noise is not carried out over a larger period but over a part of it, namely 1 hour.
In Wallonia, the propagation model ISO-9613-2:1996 is to be applied for industrial sources [12]. For wind turbines a report commissioned by the Walloon Government has been made available, in which a proposal has been made for a harmonised calculation model [13]. The recommendation is usually followed in Wallonia. It is recommended to use the turbine's sound power for a wind speed of 10 m/s at a height of 10 m. Wallonia has a short assessment period of 1 hour. The report states that temporary increases due to the phenomenon of amplitude modulation may occur within this period. To take this effect into consideration, it is recommended that a weighting of 1 dB be added to the noise level. Just like Germany, it is proposed that the alternative calculation of attenuation due to the ground effect as described in section 7.3.2 of ISO-9613-2:1996 is made use of. In Wallonia, there is no requirement to use an allowance for uncertainties in the calculation of the noise level because it is assumed that this is discounted in the (conservative) ground effect. In Wallonia, there is a directive to reduce visual impact from wind turbines [14]. The distance to any habitat should be at least 4 times the total height of wind turbines. A smaller distance is permitted in rural areas, provided it is not less than 400 m.

7. Model calculations

The difference in standards and calculation methodologies means that different distances from homes must be observed when making a location choice for new wind turbines. To better understand this, model calculations have been carried out with the five calculation methodologies discussed above. Two scenarios have been investigated. The first scenario is a single wind turbine in a rural area with a few homes in the vicinity. The second scenario is a wind farm with 5 turbines in a line, which will be located parallel to a small residential centre. The distance between the wind turbines in this scenario is 400 m. The scenarios have been chosen due to their simplicity. The second scenario is also considered to be a good representation of larger wind farms.
With these models, the noise has been calculated in steps of 25 m from the receiver to the wind turbine. The calculated values are then subtracted from the limit value in force for the type of area in the relevant country. The assumptions made in the calculations are summarised in Table IV.
The results of the model calculations for scenario 1 are shown in Figure 2. The *x*-axis shows the distance between source and receiver in meters; the *y*-axis shows the difference between the maximum permissible value and the calculated noise level. The points of intersection of the curves at $y = 0$ indicates the minimum distance that must be maintained with respect to housing.

Table V: assumptions for the calculations

configuration		
scenario 1	single turbine	
scenario 2	5 turbines in a line	
wind turbine(s)		
P_{rated}	2.3 MW	
L_{WA} at P_{rated}	104.5 dB(A)	
Hub height	108 m	
Rotor diameter	82 m	
L_{WA} used		
Denmark	102.9 dB(A) at 6 m/s	
The Netherlands	100.1/100.2/100.4 dB(A)[1)]	
Germany	106.5 dB(A), 2 dB margin	
Flanders	104.5 dB(A)	
Wallonia	105.5 dB(A), 1 dB margin	
area type		
scenario 1	agricultural/rural	
scenario 2	residential/urban	
porous ground	scenario 1	scenario 2
The Netherlands	100%	50%
Flanders	80%	50%
noise limit used	scenario 1	scenario/2
Denmark	42 dB(A)	37 dB(A)
The Netherlands	47 dB(A)	47 dB(A)
Germany	45 dB(A)	40 dB(A)
Flanders	43 dB(A)	39 dB(A)
Wallonia	43 dB(A)	40 dB(A)[3)]
assessment height	4 m	

1) year average for the day/evening/night, calculated with the data from Figure 1
2) according to regulation for farmland
3) summer nights are considered normative

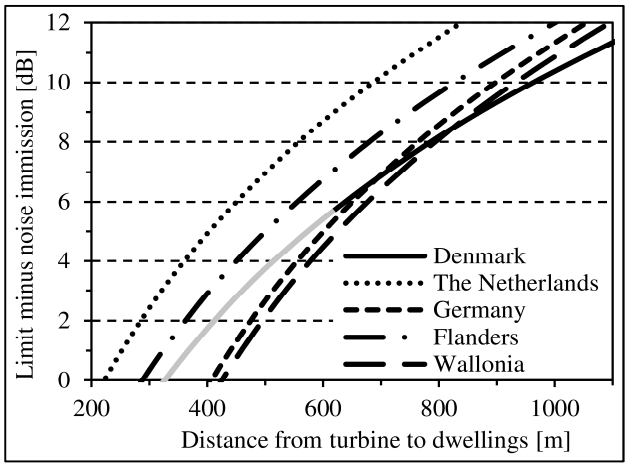

Figure 2: calculation results for scenario 1: single wind turbine in a rural area

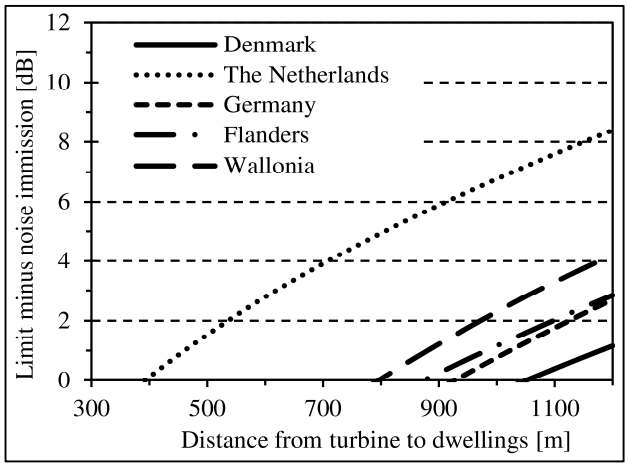

Figure 3: calculation results for scenario 2: five turbines arranged in a line parallel to a residential area

Figure 2 shows that the Dutch scheme in rural areas is the most flexible. The wind turbine in scenario 1 meets the standard at a minimum distance of 220 m. This could be less if the turbine were to be built further inland. If the location were to be windier, a slightly greater distance must be maintained. The figure also shows that the German and Walloon regulations are very similar. In these countries, wind turbines according to scenario 1 may not be closer than 400 m to agricultural homes of third parties.

The Danish distance rule implies that a setback distance of 600 m has to be maintained. For scenario 1, the noise limits would allow a shorter distance and are therefore not normative. In the other countries, there is no distance limitation that is less than 400 m, with the exception of a limited number of German states.

The ground effect plays an important role in the observed differences. In Germany and Wallonia, the ground effect is calculated using the alternative method of ISO-9613:1996. That calculation method can lead to a difference of more than 3 dB for porous ground.

The results of the calculations for scenario 2 are shown in Figure 3. Figure 3 shows that, in the Netherlands, the wind farm can be developed 400 m away from residential areas. In other countries, the distance should be at least 800 m. The mutual differences between those countries are ±1.5 dB. The difference with the Netherlands can be explained to a large extent because there are no extra standards for residential areas in the Netherlands.

8. Conclusion

The four countries considered in this article have several different noise standards for wind turbines. From two sample calculations, it was clear that the Dutch scheme is the most flexible of the four presented.

References

[1] Bekendtgørelse om støj fra vindmøller, Miljøministeriet, BEK nr 1284, 15/12/2011

[2] Søndergaard, B., Low Frequency Noise from Wind Turbines, Grontmij A/S, Ref. 35.6418.03, 01/2014

[3] Besluit van 19 oktober 2007, houdende alg. regels voor inr. (BARIM), Stbl 2010, nummer 749, 14/10/2010

[4] Regeling van 9 november 2007, nr. DJZ2007104180, houdende alg. regels voor inr. (RARIM), 20/12/2010

[5] Windtool, available at http://www.mp.nl/rekentool, Accessed 01/03/2015

[6] Technische Anleitung zum Schutz gegen Lärm - TA Lärm, GMBl Nr. 26/1998 S. 503, 26/08/1998

[7] Materialien Nr. 63 Windenergieanlagen und Immissionsschutz, LUA Nordrhein-Westfalen, 2002

[8] Besluit van 6 feb 1991 houdende vaststt. van het Vlaams regl.betr. de milieuvergunning (VLAREM I), 4/10/2014

[9] Besluit van juni 1995 houdende Algemene en Sectorale bep. inz. milieuhygiëne (VLAREM II), 4/10/2014

[10] Toelichtingsbijlage bij de aanvraag van een milieuvergunning, VLAREM-01B1-140917

[11] Arrêté portant conditions sectorielles relatives aux parcs d'éoliennes d'une puissance totale supérieure ou égale à 0,5 MW, 13/02/2014

[12] Arrêté relatif à l'évaluation et à la gestion du bruit dans l'environnement, M.B. 12.07.2004, 11/05/2007

[13] Tréfois, V., Rédaction d'une norme et d'une méthode acoustique prévisionelle harmonisée pour le bruit des éoliennes, ICA Acoustic Engineers, 3/10/2012

[14] Cadre de référence pour l'implantation d'eoliennes en region wallone, Gouvernement Wallon, 11/07/2013