Assessment of low-frequency noise due to wind-turbines in relation to low-frequency background noise

Eugène de Beer (e.debeer@peutz.nl)
Peutz bv, Paletsingel 2, 2718 NT, Zoetermeer, The Netherlands.

Summary
Assessment of low-frequency noise (LFN) is one of the major aspects in the Environmental Impact Assessment for a projected wind farm at the city of Utrecht. In the Netherlands there are no legal noise limits for LFN. There are only several guidelines for the assessment of LFN. In this Environmental Impact Assessment the low-frequency noise at the dwellings due to this projected wind farm is not only calculated but also a comprehensive inventory of the prevailing low-frequency ambient noise has been made. Simultaneous with de LFN the wind-speed and wind-direction have been measured during 3 months. This area-specific information (low-frequency background noise at a certain wind speed and direction) has been used for the assessment of the LFN due to the projected wind farm besides a comparison with the Dutch guidelines as well as the Danish legal LFN limits. The aim of measuring the LFN is to investigate the present low-frequency background noise (due to road traffic, industry and shipping) and the possible increase of LFN annoyance due to the projected wind farm. In this paper a comparison is made between the measured background noise and the several low-frequency noise limits and guidelines.

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1. Introduction

In 2013 the municipality of Utrecht (The Netherlands) investigated the possibility to operate a wind farm on an industrial area surrounded by residential areas with dwellings as close as 125 meters. In figure 1 an overview is given of the industrial area “Lage Weide” (red) and several residential areas (blue). At the south of the industrial area a mayor highway (A2) is situated. In the present situation there are no complaints about LFN know in this area.

To make a well-balanced decision an Environmental Impact Assessment has been made. Low-frequency noise (LFN) is one of the major concerns of the local residents. Therefore an important aspect of the Environmental Impact Assessment is LFN annoyance due to the wind farm.
Low frequency noise is technically defined as noise within the frequency range of 10 – 160 Hz. LFN is caused by industry, road traffic, shipping and also (strong) wind induced LFN from trees, vegetation and buildings.
In the Netherlands there are no legal noise limits for LFN. There are only several guidelines for the assessment of LFN. To make a good assessment of the LFN not only the LFN levels due to the projected wind farm at the dwelling are calculated and assessed with the several guidelines and the Danish noise limit[5,6]. But also the low-frequency background noise has been measured in the living area during a relative long period of 3 months. The measured LFN levels are incorporated in the total assessment of the LFN annoyance.

Figure 1: Overview industrial area Lage Weide at Utrecht

2. Noise limits

2.1. General

As mentioned earlier there are no legal noise limits for LFN in the Netherlands. For the assessment of LFN in the Netherlands two guidelines mostly are used. One guideline is from the Nederlandse Stichting Geluidshinder (Dutch Foundation Noise Annoyance) and describes how to investigate the audibility of LFN. The other guideline is known as the Vercammen-curve and describes the LFN levels where annoyance can occur.
In 2012 new regulation in Denmark entered into force with a new mandatory limit for LFN for wind turbines. Although this regulation is not legally applicable for situations in the Netherlands, this regulation can be used to assess the LFN. All these limits are related with the indoor noise level inside dwellings.

2.2. Guidline NSG

The low frequency noise guideline of the Nederlandse Stichting Geluidshinder (NSG)[1] contains a reference curve which is based on the 90%-hearing threshold of representative group older people (50 to 60 year). A hearing threshold of 90% means that 90% of a group of people can't hear this noise level and 10% of the group can just hear this level. In table I the NSG-reference curve is given.

When none of the 1/3 octave band values of the reference curve is exceeded no LFN is audible and therefore no annoyance will occur. When one on more of the 1/3 octave band values is exceeded LFN is audible and the degree of annoyance can be predicted by the degree of exceeding of the reference value.

2.3. Vercammen-curve

The Vercammen-curve[2,3,4] is based on possible annoyance of LFN. In tabel II the Vercammen-curve is given. The way of assessment with the Vercammen-cure is the same as with the NSG-curve. When none of the 1/3 octave band values of the Vercammen curve is exceeded there is no relevant LFN annoyance.When one or more 1/3 octave band values is exceeded there can be some LFN annoyance.

2.4. Danish noise limit

The new Danish regulation[5,6] complements the previous noise limits for wind turbines with a new mandatory limit for the low frequency noise, which is 20 dB A-weighted level of the calculated indoor sound level in the 1/3 octave bands from 10 up to 160 Hz. This noise limit of 20 dB(A,LF) applies to wind-speeds of 6 and 8 m/s. In this regulation a calculation method is given with a standard sound insulation (level difference) to calculate the indoor noise levels. In table III the used sound insulation is given. This sound insulation is based on 26 measurements in 14 different dwellings, representative of Danish buildings at the countryside and in suburban areas.

Table I. NSG-reference curve

1/3 octave band in Hz	*20*	*25*	*31.5*	*40*	*50*	*63*	*80*	*100*
L_{eq} in dB	74	62	55	46	39	33	27	22

Table II. Vercammen-curve

1/3 octave band in Hz	*10*	*12.5*	*16*	*20*	*25*	*31.5*	*40*	*50*	*63*	*80*	*100*	*125*
L_{eq} in dB	86	82	76.7	70.5	64.7	59.4	54.6	50.2	46.2	42.5	39.1	36.1

Table III. Sound insulation (level difference) in dB accordance Danish regulation

1/3 octave band in Hz	*10*	*12.5*	*16*	*20*	*25*	*31.5*	*40*	*50*	*63*	*80*	*100*	*125*	*160*
D in dB	4.9	5.9	4.6	6.6	8.4	10.8	11.4	13	16.6	19.7	21.2	20.2	21.

3. LF BACKGROUND NOISE MEASUREMENTS

3.1. Locations and method

To obtain a representative image of the already present low frequency noise levels in the living area around industrial area "Lage Weide" (Utrecht) three locations were chosen (see also figure 2).

Location A – Nearby the highway A2. Along this part of the highway an acoustical screen is present. Although the noise level in dB(A) is relative low due to the screen, relative high LFN-levels were expected at this location.

Location B – A location at relative great distance of LFN-sources and a lot of screening by the surrounded houses. Therefore low LFN-levels were expected at this location.

Location C – At short distance of a busy road, the industrial area and the shipping in front of the houses. High LFN-levels were expected at this location.

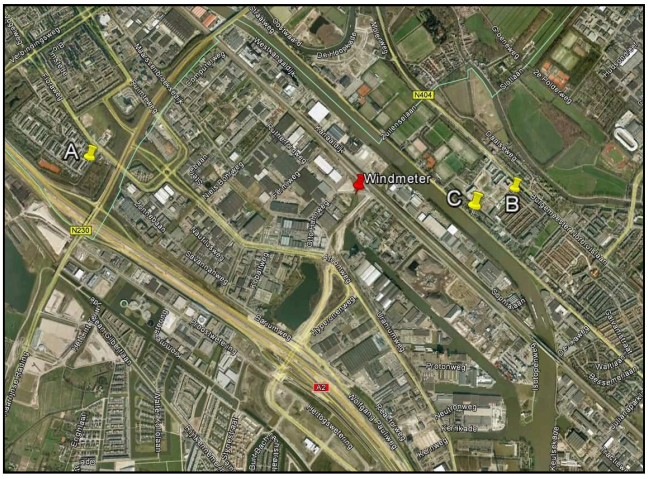

Figure 2: Overview measurement locations

During 3 months the noise levels were measured at the above mentioned three locations. The measurement were carried out with a monitoring system developed by Peutz. These monitoring systems measured every second an equivalent noise level that has been (real-time) analyzed in 1/3 octave bands levels and written to a MySQL database connected to the internet. Also the wind-speed and wind-direction were measured every second and written to the same MySQL database.
All the wind-data has been divided in blocks of 10 minutes. Of these 10 minute time blocks the average wind-speeds and wind-directions has been determined and the measured LFN levels are tagged with this wind-data.

3.2. Results

From all the 1/3 octave bands values the A-weighted noise level has been calculated of the 1/3 octave bands from 10 up to 160 Hz (dB(A,LF)). In figure 3 the measured L_{eq} in dB(A,LF) at location A are given for the different wind-speeds, wind-directions and period (day, evening and night).

Figure 3 shows that there are no big differences between the measured LFN-levels in the different wind-directions. Only in the night period the measured levels with wind-direction SW are a little higher than the other wind-directions. This is due to the highway which is situated at the SW site of location A. The differences between the wind-directions at the locations B and C are even smaller. It can be concluded that the wind-

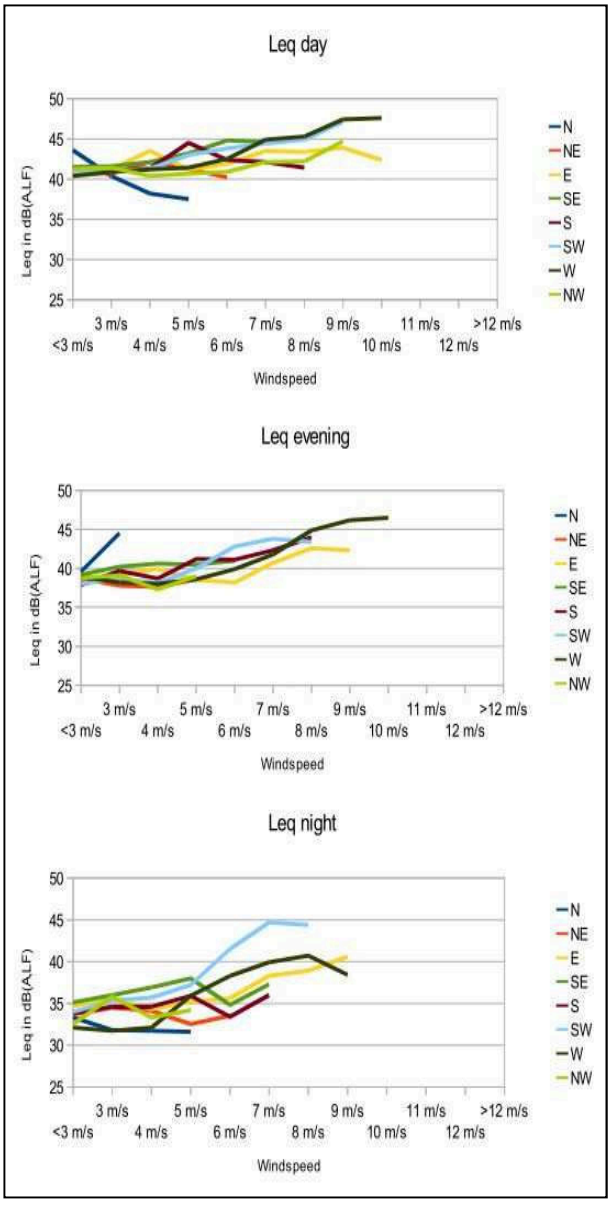

Figure 3: Measured L_{eq} in dB(A,LF) at location A

direction is not very determinative for the measured LFN-level and is therefore not further considered.

In figure 4 the measured LFN-levels (L_{eq} and L_{95} in dB(A,LF)) at all 3 locations are plotted against the wind-speed. Figure 4 shows that the L_{95} are more depended on the wind-speed than the L_{eq}. At location C with a lot of foreground noise of the busy road in front of the measurement location the L_{eq} in dB(A,LF) is hardly dependent on the wind-speed.

In table IV the total L_{eq} and L_{95} in dB(A,LF) is given for the day, evening and night-period, measured during the 3 months and without any division into wind-direction and wind-speed.

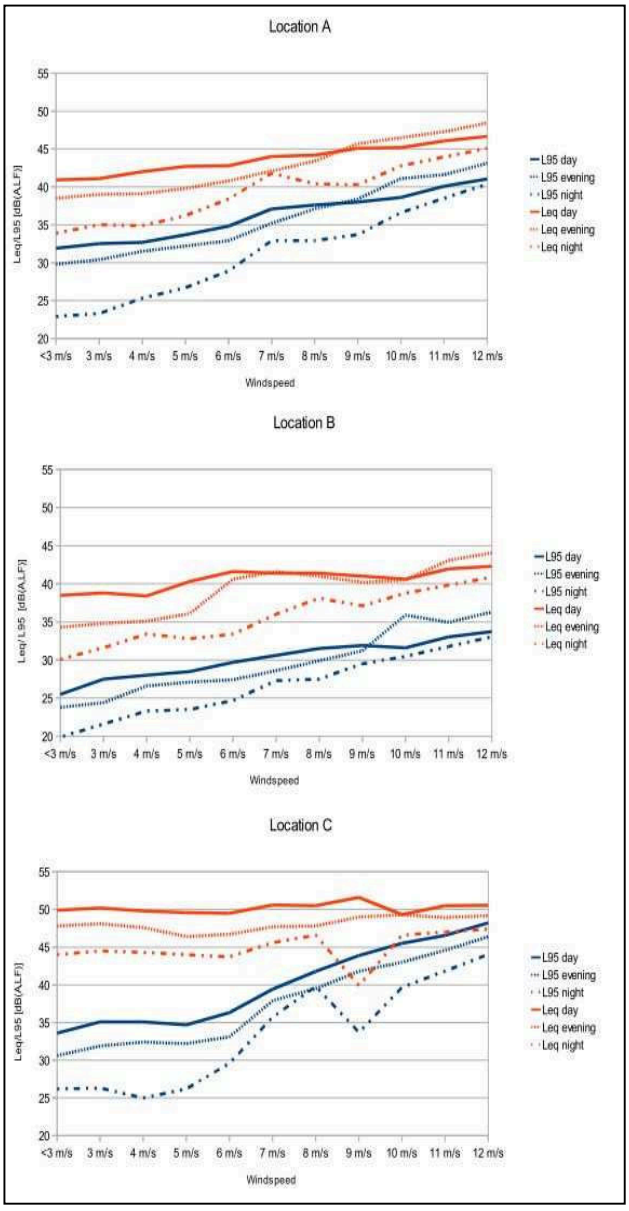

Figure 4: Measured L_{95} and L_{eq} in dB(A,LF)

Table IV. Total $_{Leq}$ en L_{95} in dB(A,LF)

Concerns	*L_{eq} in dB(A,LF)*			*L_{95} in dB(A,LF)*		
Location	*A*	*B*	*C*	*A*	*B*	*C*
Day	44,1	40,8	50,2	37,2	20,8	42,8
Evening	44,2	40,3	48,1	38,1	31,7	40,7
Night	40,8	36,9	45,3	34,5	28,4	37,9

4. COMPARISON WITH GUIDELINES AND LEGAL NOISE LIMITS

4.1 Comparison with guideline NSG

To compare the measured LFN levels outside with the reference curve of NSG first the measured levels must be corrected with the sound insulation of the dwellings. The used sound insulation is based on a theoretical approach with a reduction of 15 dB at 100 Hz and descending for the lower frequencies with 3 dB/octave. The measured LFN levels are also corrected for ground-reflection.

The obtained indoor LFN-level of every 10 minute time block with a certain wind-speed is assessed to the NSG-reference. Three relevant wind-speed categories are considered, namely:

- low: wind-speed between 3 and 6 m/s
- medium: wind-speed between 7 and 9 m/s
- high: wind-speed between 10 and 12 m/s

In table V the percentages of 10 minute blocks are given where the LFN-level exceeds the NSG-reference curve.

Table V. Percentage of the time exceeding the NSG-reference curve.

Location A			
Wind-speed	*day*	*evening*	*night*
Low	100%	100%	82%
Medium	100%	100%	100%
High	100%	100%	-*
Location B			
Low	97%	90%	39%
Medium	100%	100%	78%
High	100%	100%	-*
Location C			
Low	100%	100%	94%
Medium	100%	100%	100%
High	100%	100%	-*

* Not enough data for assessment

Table V shows that the measured low frequency background noise in this environment (centre of a

city with a lot of industrial, road, railway and shipping noise) almost always exceeds the NSG-reference curve. Only at low wind-speeds at relative quiet location (location B) there is no continues exceeding.

4.3. Comparison with Vercammen-curve

To compare the measured LFN levels outside with the Vercammen-curve the measured levels are be corrected with the sound insulation of the dwellings at the same way as the assessment with the NSG-curve.

In table VI the percentages of 10 minute blocks are given where the LFN-level exceed the Vercammen curve.

Table VI. Percentage of the time exceeding the Vercammen curve.

Location A			
Wind-speed	*day*	*evening*	*night*
Low	89%	60%	19%
Medium	98%	96%	76%
High	100%	100%	-*
Location B			
Low	49%	24%	9%
Medium	71%	45%	13%
High	75%	100%	-*
Location C			
Low	97%	89%	51%
Medium	99%	99%	75%
High	100%	100%	-*

* Not enough data for assessment

Table VI shows that the measured low frequency background noise in this environment almost always exceeds the Vercammen curve at high wind speed. At lower wind-speeds there is a dependence of the location (location B relative quiet and location A and C relative noisy) and the period of the day. At location B in the night-period there is limited exceeding of the Vercammen curve.

4.4. Comparison with the Danish noise limit

The measured LFN levels outside are also assessed with the Danish noise limit. Therefore the measured low frequency noise levels are corrected with the insulation (reduction) as give in the Danish regulation. In table VII the percentages of 10 minute blocks are given where the LFN-level exceed the Danish noise limit of 20 dB(A,LF) inside a dwelling.

Table VII. Percentage of the time exceeding the Danish noise limit.

Location A			
Wind-speed	*day*	*evening*	*night*
Low	77%	28%	8%
Medium	95%	88%	48%
High	100%	100%	-*
Location B			
Low	22%	4%	2%
Medium	47%	23%	10%
High	75%	100%	-*
Location C			
Low	96%	80%	41%
Medium	97%	94%	63%
High	100%	100%	-*

* Not enough data for assessment

Table VII shows that the measured low frequency background noise in this environment almost always exceeds the Danish noise limit at high wind speeds. At lower wind-speeds there is a dependence of the location (location B relative quiet and location A and C relative noisy) and the period of the day.

5. Conclusions

In the present situation there are no complaints known about LFN in this neighbourhood. The measured LFN levels in the present situation are considerably. These noise levels are limited depending on the wind-direction. The LFN levels are certainly depending on the location, wind-speed and period of the day.
Very regular the measured LFN levels exceed the Dutch guidelines for audibility and annoyance of LFN. Even the Danish legal noise limit of 20 dB(A,LF) is very regular (63% up to 95% of the time) exceeded in the present situation at wind-speed of 6 and 8 m/s (medium wind-speed) at the most noisy location C. Even at a relative quite location (location B) the measured LFN exceed the Danish noise limit regular (10% up to 47% of the time) at wind-speed medium.
In order to ensure there is no (unacceptable) annoyance of LFN in the Environmental Impact Assessment the Danish regulation is used as absolute admissibility criterion. No exceeding of the Danish noise limit by the LFN of the wind farm ensures that there is no relevant increase of

the LFN levels at the surrounding dwellings of the projected wind farm.

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