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Low Frequency Noise Proposed Wind Farm in Maastricht, The Netherlands

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Summary
In Maastricht, The Netherlands, a new wind farm was proposed adjacent to an existing wind farm and industrial site in Belgium. As part of the environmental impact assessment in the planning phase, ARCADIS undertook a noise modelling study to evaluate cumulative noise levels produced by the new and existing sites. These calculations were conducted in accordance with both Dutch and Belgian regulations and compared against both national noise regulation limits. Low frequency noise levels were also assessed according to Dutch guidelines.

On January 1st, 2012, legislation on low frequency wind turbine noise was approved and enforced in Denmark. Opponents of the Dutch wind farm stated the noise levels should be compared against the new, state-of-the-art Danish noise limits for low frequency noise. Calculations showed these noise limits were in compliance at the Dutch dwellings, but opponents asked the City Council of Maastricht for a second opinion from the Danish Aalborg University. The City Council decided to please the opponents and requested a review by the Danish university. The results of this report showed ARCADIS had understood and applied the new Danish legislation correctly. However, it was further stated that the prescribed Danish assessment method was not correct and new calculations were made. This interesting case describes the assessment by Dutch, Belgian, and Danish methods and gives insight into the Danish discussion on their new low frequency noise legislation.

1. Introduction
On the outskirts of the City of Maastricht, The Netherlands (NL), a new wind farm was proposed adjacent to an existing wind farm and industrial site in Belgium (B). The proposed wind farm is part of the sustainable energy plant Limburg. This energy plant consists of a wind farm, a biomass plant and a solar plant in Maastricht, and a wind farm, a biomass plant and a solar plant in Venlo. The locations for the different elements of these plants were designated in a bid book by the Municipality of Maastricht and the Municipality of Venlo. After a European public procurement procedure by the Province of Limburg, the technical services provider Imtech was selected to develop and build the sustainable energy plant Limburg.

As part of the environmental impact assessment in the planning phase, ARCADIS undertook a noise analysis study to evaluate the combined noise levels produced by the new and existing wind farms. The calculations were conducted in accordance with both Dutch and Belgian (Flemish) regulations and compared against both

national noise limits. Low frequency noise levels were assessed according to Dutch guidelines. Later in the process they were also assessed according to new Danish legislation on low frequency wind turbine noise.

2. Situation

On the outskirts of the City of Maastricht in the south of The Netherlands a small wind farm of four wind turbines was proposed. These wind turbines were planned on a future industrial site just adjacent to the international border shared with Belgium. Just across the border in Belgium, there are already four existing wind turbines. These are located on an existing industrial site on the outskirts of the City of Lanaken. Figure 1 gives a view of the proposed and existing wind turbines.

The existing Belgian wind farm consists of four 2 megawatt turbines type Vestas V80-2.0 MW with a hub height of 100 meters (m). These turbines have a maximum sound power level (L_{WA}) of 105.2 dB(A). The year average sound power level (L_E) of these turbines at this specific location is 101.9 dB(A) during the day and evening and 102.2 dB(A) during the night.

The new wind farm, as proposed in September 2011, consists of four turbines with an installed power of a maximum 3.2 megawatt (MW) each, a hub height of maximum 135 m and a maximum sound power level (L_{WA}) of 107 dB(A). At the specific location this leads to a year average sound power level (L_E) of the new turbines of 103.0 dB(A) during the day, 103.2 dB(A) during the evening and 103.4 dB(A) during the night. For the environmental impact assessment, three possible layouts of the wind farm were considered.

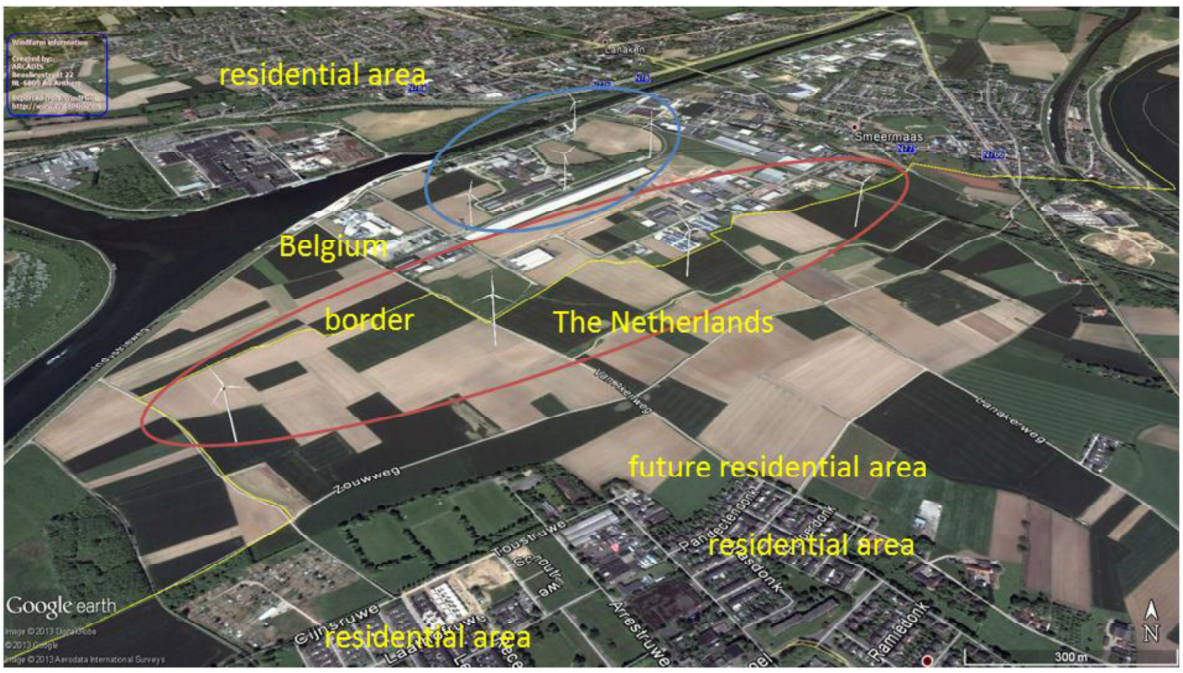

Figure 1. View of the four proposed wind turbines in The Netherlands and to the north, just across the border, four existing wind turbines on an industrial site in Belgium.

The nearest noise sensitive locations are a residential area in Maastricht (NL) south of the proposed wind farm, a residential area in Lanaken (B) north of the existing wind farm, a few dwellings on the Belgian industrial site, and some dwellings around

the wind farms on the outskirts of Maastricht and Lanaken. The residential area in Maastricht is partially being redeveloped and the zoning plan allows additional dwellings at the northern edge of the residential area. This means that new dwellings might be situated closer to the wind farm than the existing dwellings.

A simulated visualisation of the proposed wind farm is shown in Figure 2.

Figure 2. Visualisation of (part of) the new wind farm with the industrial site in the background showing one of the existing Belgian wind turbines.

3. Legislation wind turbine noise in The Netherlands and Belgium

3.1 Dutch legislation

The Netherlands has specific legislation on noise from wind turbines [1]. The current legislation has been implemented on January 1st, 2011, together with a special regulation for measuring and calculating wind turbine noise [2]. The Dutch code requires a calculation based on the actual wind distribution in order to determine annual average noise levels L_{den} and L_{night}.

L_{den} is the day-evening-night level in dB as defined by the following formula:

$$Lden = 10\log\left(\frac{12 * 10^{\frac{Lday}{10}} + 4 * 10^{\frac{Levening+5}{10}} + 8 * 10^{\frac{Lnight+10}{10}}}{24}\right)$$

L_{day} is the A-weighted long-term average sound pressure level determined over all the daytime periods of a year and $L_{evening}$ the A-weighted long-term average sound pressure level determined over all the evening time periods of a year. L_{night} is the A-weighted long-term average sound pressure level determined over all the night time periods of a year. The daytime period is from 7 a.m. to 7 p.m., the evening period is from 7 p.m. to 11 p.m. and the night time period is from 11 p.m. to 7 a.m.

The calculations require to determine the year average sound power level per day, evening and night in octave bands from 31.5 to 8000 Hz. A meteorological correction is taken into account if the distance from a turbine is larger than 10 times the hub

height plus the receiver height. This correction is calculated on the basis of the hub height, the receiver height, and the direction and distance from the receiver position relative to the turbine positions.

The noise limits at dwellings and other noise sensitive buildings are:

- Lden: 47 dB;
- Lnight: 41 dB.

The Dutch authorities can chose to take cumulative effects with neighbouring wind farms into account, but this is not obliged. Furthermore, these authorities can also decide to set different noise limits taking special local circumstances into account.

3.2 Belgian legislation

The Belgian Municipality of Lanaken is situated in the Flanders region of Belgium. At the time of the study for the proposed wind farm the noise of wind turbines was regulated by means of a Ministerial Circular [3]. However, on 15 July 2011 the Flemish government in principle approved new environmental regulations for wind turbines [4]. At request of the Flemish authorities the new legislation was already applied to the proposed wind farm. Officially, the new legislation entered into force on 1 January 2012.

For noise calculations, the ISO-9613-2 method is used. The noise levels are calculated in 1/3 octave bands beginning at 50 Hz, or can be calculated in octave bands beginning at 63 Hz. The sound power level used is to be determined at 95 % of the nominal power from the wind turbine. The calculations assume downwind conditions. A meteorological correction is not allowed.

The target values for wind turbine noise in Flanders are summarized in Table 1. If the background noise level is higher than the values as stated in this table, then the noise limit is equal to the background noise level. In this situation a setback distance of a minimum of 3 times the rotor diameter is to be taken into account.

Table 1. Target values for wind turbines in Flanders, Belgium

Area	Target value in dB(A) in open air		
	Day	Evening	Night
residential areas, areas for recreation residence	44	39	39
rural areas, residential areas at less than 500 m from industrial areas, recreational areas	48	43	43
industrial areas	60	55	55
other areas	44-55	39-50	39-50

3.3. Guidelines low frequency noise

The Netherlands and Belgium have no legislation on low frequency noise. However, in The Netherlands it is quite common to assess low frequency noise by comparing them against the NSG-curve and Vercammen-curve. These curves are shown in Figure 3.

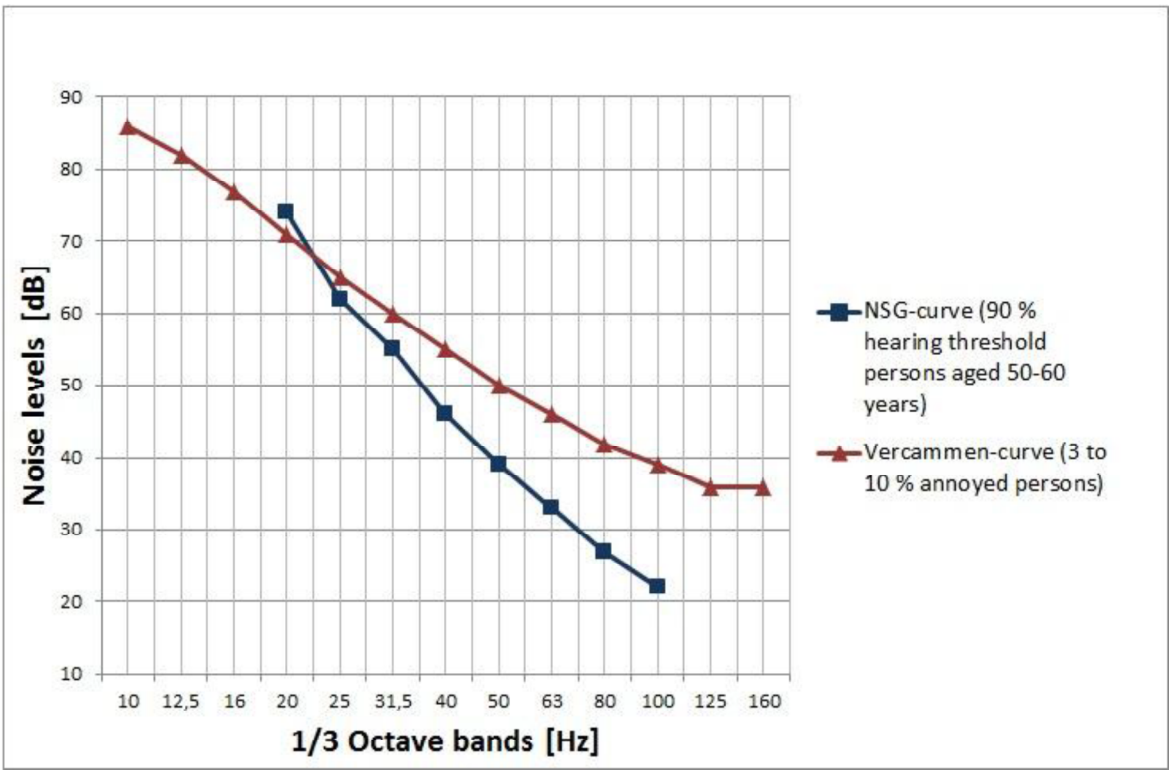

Figure 3. NSG-curve and Vercammen-curve for assessment of low frequency noise.

The NSG-curve is defined in the low frequency noise guideline of the Dutch Foundation against Noise Pollution NSG [5]. The main goal of the NSG guideline is to have a tool to objectively assess complaints about low frequency noise. The NSG-curve is based on the 90% hearing threshold of a representative group of elderly persons (aged 50 to 60 years). This criterion was chosen by the NSG because research showed complaints about low frequency noise mainly came from elderly people. Therefore, the NSG-curve is mainly used to assess the audibility of low frequency noise. It does not rate the annoyance.

To assess annoyance by low frequency noise, in The Netherlands the Vercammen-curve is most commonly used. This curve is based on 3 to 10 % range of annoyed persons by low frequency noise [6]. Since a ruling of the Administrative Jurisdiction Division of the Council of State [7] in 2006 stating the Vercammen-curve is a suitable method to assess annoyance by low frequency noise, this curve has gained importance.

4. Assessment wind turbine noise

4.1 Cumulative noise levels Belgian and Dutch wind farms

As part of the environmental impact assessment (EIA) the noise levels of the proposed wind farm were determined for three possible wind turbine layouts. The calculations took into account the cumulating effect of the proposed wind farm along with the existing Belgian wind farm.

The noise levels were assessed for the existing and future residential areas in Maastricht (NL), the residential area in Lanaken (B), the dwellings on the industrial site and the nearest dwellings around the wind farms on the outskirts of Maastricht and Lanaken. Figure 4 shows five representative receptor positions.

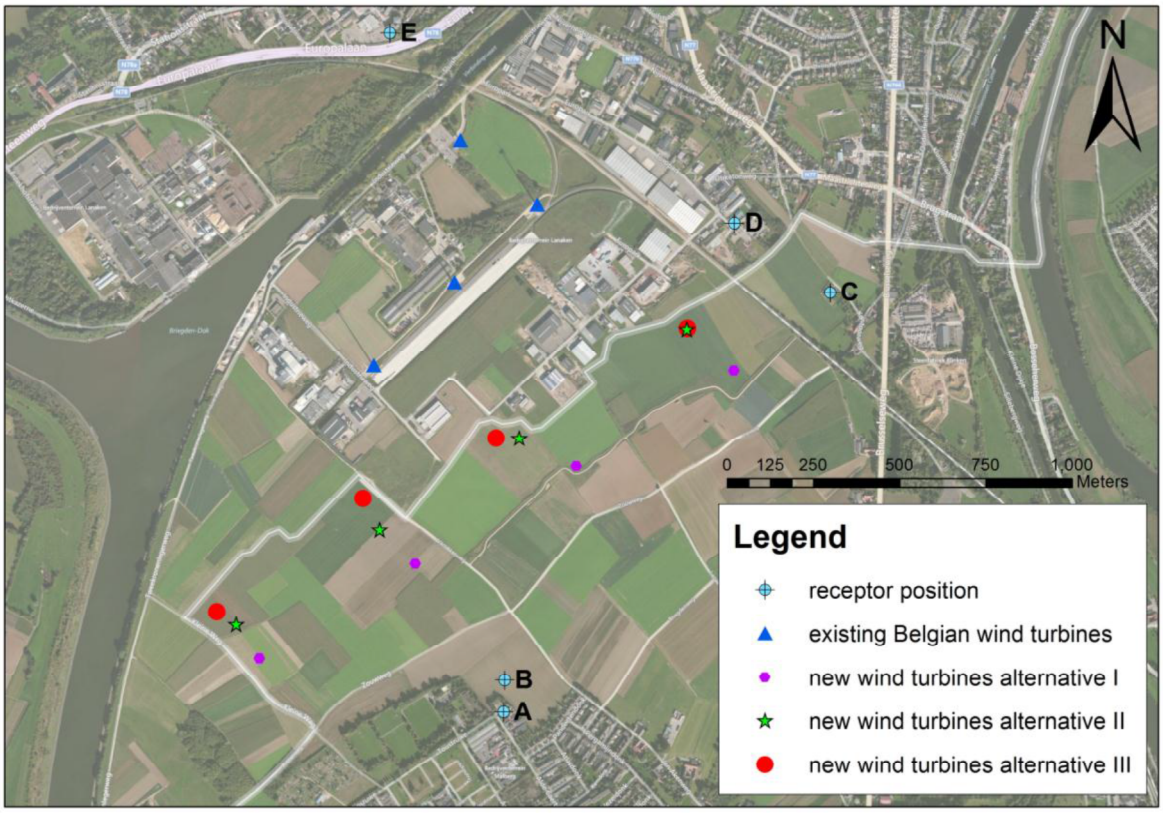

Figure 4. View of the existing wind turbines in Belgium, three possible wind turbine layouts for the proposed wind farm in The Netherlands, and five representative receptor positions at residential areas or single dwellings near the wind farms.

For the Dutch dwellings the noise levels were evaluated according to the Dutch regulations. For the Belgian dwellings the noise levels were evaluated according to both the Dutch as well as the Belgian (Flemish) regulations. Table 2 shows the results at the five receptor positions.

Table 2. Cumulative noise levels existing Belgian and proposed Dutch wind farm according to the Dutch and Belgian legislations and regulations for wind turbine noise for three possible wind turbine layout alternatives [8].

Position	Location	Noise levels three possible turbine layout alternatives					
		The Netherlands				Belgium	
		L_{den} [dB]		L_{night} [dB]		L_{Aeq} at 95% nominal power [dB(A)]	Noise limit [dBA)]
		Level	Limit value	Level	Limit value		
A	residential area Maastricht (NL)	45-47	47	38-40	41	--	--
B	future residential area Maastricht (NL)	46-**48**	47	**39-41**	41	--	--
C	dwelling on the outskirts of Maastricht (NL)	46-**48**	47	40-41	41	--	--
D	dwelling on the industrial site in Lanaken (B)	**48-50**	47	**42-44**	41	46-47	55
E	residential area Lanaken (B) at less than 500 m from industrial area	46-47	47	40	41	**44**	43

The results show that for one alternative the noise level exceeds the Dutch noise limit at position B at the edge of a future residential area and at position C near a few dwellings on the outskirts of Maastricht. For all three alternatives the noise levels exceed the Dutch limit value at a dwelling on the Belgian industrial area. The noise levels at this dwelling do meet the Flemish target value. At the edge of the residential area in Belgium the noise levels meet the Dutch noise limit, but do just exceed the Flemish target value. However, since at this location the background noise levels exceed the target value (see Table 3) higher noise levels can be permitted.

Table 2 shows that assessment according to Dutch and Flemish legislation leads to different conclusions. The main reason is that in Flanders the limit values depend on the location (environment) of the dwelling. In The Netherlands the standard noise limits are independent of the location of a dwelling.

<u>Note:</u>
Above, we compared the cumulative noise levels of the Dutch and Belgian wind farm with the standard Dutch limit values and Flemish target values. However, legally the Dutch limit values only apply to the Dutch wind farm and the Flemish target values only to the Belgian wind farm.

4.2 Cumulative noise levels wind farms and other existing and new noise sources

The dwellings around the proposed wind farm are already subjected to noise from not only the already present Belgian wind farm, but also the existing Belgian industrial site and (less important) road and rail traffic. When the future industrial site in The Netherlands is being developed, this will also add to the noise levels. As part of the environmental impact assessment we also considered the cumulative effects with these existing and planned noise sources. The cumulative noise levels – taking

into account differences in dose-effect relationships[1] – are shown in Table 3. These results show the new wind farm adds 2 to 3 dB to the existing noise levels at the Dutch dwellings. For the dwelling on the Belgian industrial site the new wind farm adds 1 to 2 dB. At the edge of the residential area in Belgium the new wind farm does not add to the existing noise levels.

Table 3. Cumulative noise levels for industrial area, Belgian wind farm, and Dutch wind farm for three possible wind turbine layout alternatives [9].

Position	Location	Noise level L_{den} [dB] Industrial area and Belgian wind farm	Noise level L_{den} [dB] Industrial area, Belgian wind farm and proposed Dutch wind farm
A	residential area Maastricht (NL)	44	46-47
B	future residential area Maastricht (NL)	45	47-48
C	dwelling on the outskirts of Maastricht (NL)	45	47-48
D	dwelling on the industrial area in Lanaken (B)	48	49-50
E	residential area Lanaken (B) at less than 500 m from industrial area	49	49

5. Assessment of low frequency noise

For the environmental impact assessment the low frequency noise of the wind farm was analysed for the wind farm alternative and the dwelling with the highest noise level. This dwelling is situated on the industrial site (position D) and is subjected to a noise level of maximum 50 dB L_{den} and 44 dB L_{night}. For this dwelling the indoor noise level was calculated in one-third octave bands for the frequency range from 20 to 100 Hz. There were two complicating factors in these calculations:

1) The turbine type had not yet been selected. This means the exact noise spectrum was not clear. We chose to use an average, somewhat conservative noise spectrum for 2 to 3 MW turbines.
2) There is a large variation in the low frequency sound insulation of dwellings. Also, for The Netherlands only very limited information is available on the sound insulation of frequencies below 100 Hz. We decided to use the lowest and highest sound insulation levels as reported in three publications for Dutch [10], Danish [11] and Swedish dwellings [12].

The calculated noise levels [9] are shown in Figure 5, together with the NSG-curve and the Vercammen-curve. This figure illustrates that the NSG-curve will most likely be exceeded for frequencies above 40 Hz and especially above 63 Hz. The Vercammen-curve will most likely not be exceeded, though the 50 Hz one-third octave band might be critical. This means that at the most critical dwelling and for the most critical alternative, the low frequency noise levels will probably be audible indoors. However, the chance that this audible noise will lead to unacceptable noise

[1] Industrial noise and road and rail traffic noise are considered less annoying than wind turbine noise. This means the noise level of industry and road and rail traffic, corrected for the differences in annoyance with wind turbine noise, add less to the cumulative noise level according to Dutch regulations than the actual noise levels would do.

nuisance is considered small. For the other alternatives and most other dwellings the noise levels are lower, which means that the chance on noise nuisance by low frequency noise is even smaller.

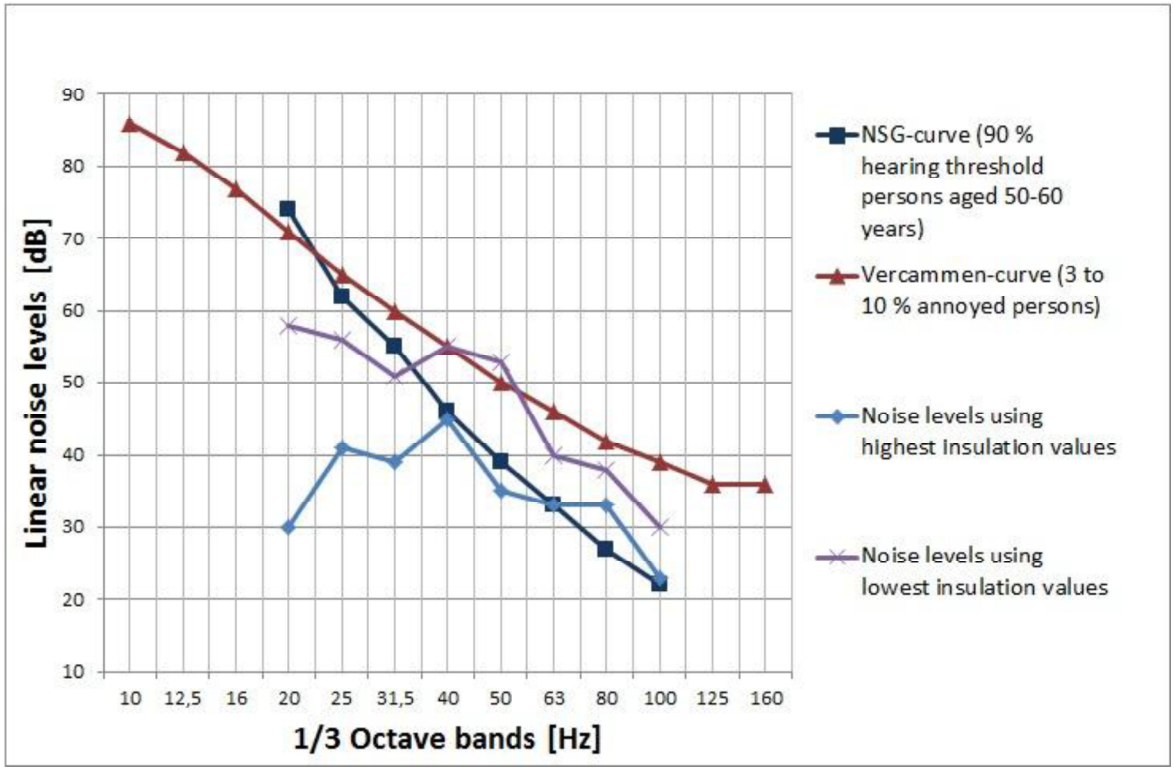

Figure 5. Calculated indoors low frequency noise level in the most critical dwelling for the most critical alternative.

6. Preferred alternative proposed wind farm

The preferred alternative for which the permits were requested (see Figure 1), possessed wind turbine coordinates which were in between the coordinates for the considered layout alternatives. Further, a reduced hub height of 119 m and a maximum sound power level (L_{WA}) of 106.5 dB(A) were chosen. The results for this alternative are equal to the lowest values as mentioned in column 3, 5 and 7 of table 2 and column 4 of Table 3. As mentioned in section 4, the Dutch limiting values legally only apply to the Dutch wind farm and the Flemish target values only apply to the Belgian wind farm. This means the preferred alternative meets the noise limits at all dwellings [13].

The low frequency noise levels for the preferred alternative showed to be a few dB's lower than reported in Figure 5 [14]. This means the low frequency noise levels are considered within compliance.

7. Danish legislation low frequency wind turbine noise

On January 1st, 2012, a revised statutory order on wind turbine noise entered into force in Denmark [15]. This new legislation includes a calculation method and limit values for impacts of low frequency noise.

The low frequency noise level L_{pALF} is defined as the total A-weighted sound pressure level in dB in one-third octave bands from 10 up to and including 160 Hz. The limit value for dwellings is 20 dB at a wind speed of 6 and 8 m/s. In contrary to regular noise limits, the limit value for low frequency noise applies to the indoor noise levels. The sound insulation (level difference) to be used in calculating the indoor noise levels in dwellings is defined in the statutory order.

The same month the Danish legislation entered into force, concerned citizens supported by a well-timed article in a regional newspaper brought attention to the Dutch wind farm and that it should also be compared against the Danish low frequency noise limit. Although the formal public participation procedure was finished, the City Council of Maastricht proved to be susceptible to their requests.

In January 2012, Imtech had already selected the wind turbine Vestas V112-3 MW for the wind farm in Maastricht. The specific noise data of this turbine in one-third octave bands was provided by Vestas. Calculations by ARCADIS showed the cumulative noise levels of the proposed and existing wind turbines also met the Danish limit values for low frequency noise, with the exception of the nearest dwelling on the industrial area (position D) [16]. At this dwelling the noise level L_{pALF} at a wind speed of 8 m/s is 1 dB over the Danish noise limit. This was deemed acceptable, because it is quite common to allow higher noise levels at dwellings on industrial sites.

The calculated noise levels in one-third octave bands from 10 to 160 Hz and the total low frequency noise level L_{pALF} are shown in Figure 6. This figure shows that when the Danish limit value is just met, the noise levels are well under the Dutch Vercammen threshold curve. Furthermore, the Danish limit value is shown to be more restrictive than the Vercammen-curve, which is based on a 3 to 10 % annoyed persons criteria.

In the calculations it was neglected that the Dutch dwellings might have a difference sound insulation value than a typical Danish dwelling.

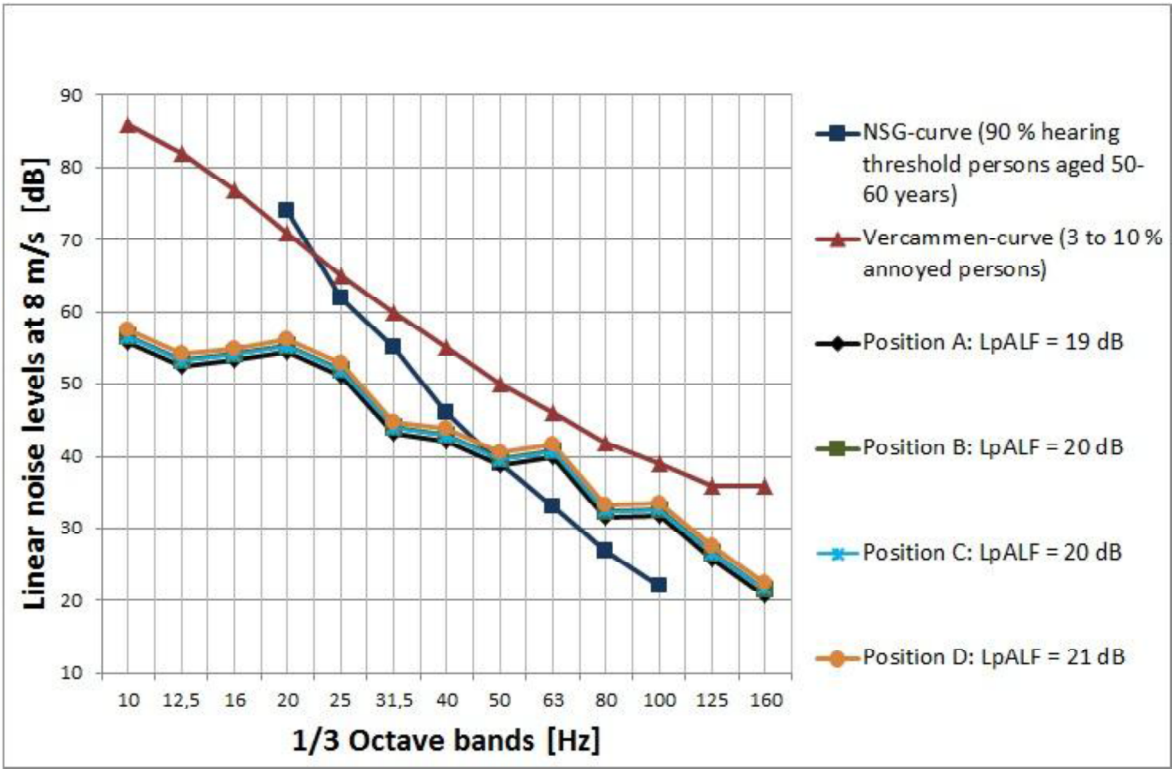

Figure 6. Calculated indoors low frequency noise level at four dwellings for the preferred alternative with Vestas V112 wind turbines.

8. Second opinion by Aalborg University

After ARCADIS delivered the noise analysis report on the assessment according to the Danish regulations, opponents of the proposed wind farm asked the City Council of Maastricht for a second opinion by professor Møller of Aalborg University. The City Council decided to please the opponents and requested this second opinion.

Møller et al. [17] concluded ARCADIS had understood and used the new Danish regulation of low frequency noise correctly.

However, next Møller et al. concluded that the calculation according to the new Danish regulation underestimates the indoor low frequency noise levels. They stated where the 20 dB limit is just met, real measurements would give values that exceed the limit by several decibels in many houses.

Their main criticism on the new Danish regulation is:

- The measurements to determine the low frequency sound insulation were not taken correctly. At low frequencies the sound varies within a room. To determine the sound insulation the indoor noise level should be measured where the annoyed person finds it loudest. They state the indoor measurements were made at arbitrary positions that were not selected for a high level. This means the determined sound insulation values are too high. Møller et al. estimate this error at about 5 dB.
- The Danish regulation defines sound insulation values which will be met in 67% of the dwellings. This means that in 33% of the dwellings higher noise levels than 20 dB might be observed. Møller et al. are of the opinion this noise level should be exceeded in not more than 10 to 20% of the dwellings. If the corresponding

lower sound insulation is used, about 3 dB higher indoor noise levels will be calculated.

Next, Møller et al. made their own calculations for the proposed wind farm in Maastricht adding 5 dB respectively 8 dB (= 5 dB + 3 dB) to the noise levels as previously calculated by ARCADIS. Of course these calculations resulted in considerably higher noise levels. Møller et al. concluded the 20 dB limit value would be exceeded in a very large area with many dwellings. They also stated they do not consider noise limits such as the Dutch based on yearly averages as suitable for wind turbine noise.

The second opinion report by Møller et al. was presented to the City Council of Maastricht by one of the opponents of the proposed wind farm. This caused a lot of confusion and unrest.

Note:
Already in 2010 and 2011 Möller et al. discussed their criticism on the new Danish regulation with Mr. J. Jakobsen of the Danish Environmental Protection Agency in the Journal of Low Frequency Noise, Vibration and Active Control [18][19]. Also, they brought their criticism forward in the public consultation procedure for the new Danish legislation. According to the Danish Ministry of Environment the underlying studies were done according to the recommended Danish measurement procedure for low frequency noise [20]. Also, the measurements were undertaken by experienced noise experts. The sound insulation as defined in the statutory order is exceeded by about 67% of the Danish dwellings. This means about 33% of the dwellings have a poorer sound insulation. The Danish Ministry of Environment indicates this choice has to be seen in relation to worst-case assumptions in the propagation calculations, like the fact that the calculations assume a wind direction from the turbines towards the dwellings and a wind speed of 8 m/s. However, these weather conditions only occur a limited part of the time. For the Danish Ministry of Environment the criticism by Aalborg University was no reason to adapt the legislation. As described before this legislation entered into force in January 2012.

The Netherlands Commission for Environmental Assessment concluded the second opinion report by Møller et al. was no reason to revise their positive advisory report on the environmental impact assessment for the proposed wind farm [21]. The Commission was of the opinion the chance of annoyance by low frequency noise had been adequately described.

9. Conclusion

The calculations showed the proposed wind farm in Maastricht met the Dutch limit values. It also met the Flemish target values. Taking the cumulative effects with the Belgian wind farm into account, the Dutch noise limit was exceeded by 1 dB at a dwelling located on an industrial area in Belgium. The Belgian target value was exceeded by 1 dB(A) at the edge of a residential area in Belgium. This was deemed acceptable because:

- Legally the Dutch noise limit values only apply to the Dutch wind farm and the Flemish target values only apply to the Belgian wind farm.
- It is quite common to allow higher noise levels at dwellings on industrial sites.

- Due to the vicinity of the residential area to the Belgian industrial area and wind farm, the background noise levels at the edge of the residential area in Belgium exceed the target value, which means a higher noise limit is applicable.

The assessment according to Dutch guidelines showed low frequency noise of the proposed Dutch wind farm and existing Belgian wind farm would probably be audible indoors within the nearest dwellings. However, the chance this audible noise would lead to unacceptable noise nuisance was considered small. This was confirmed by the fact that the cumulative noise levels also met the Danish limit values for low frequency noise. The only exception was a dwelling on the industrial area. This was deemed acceptable, because it is quite common to offer less protection to dwellings on industrial sites.

A second opinion by the Danish Aalborg University showed ARCADIS had understood and used the new Danish regulation for low frequency noise correctly. However, Aalborg University criticized the new Danish legislation on low frequency noise and was of the opinion the new regulation underestimates the actual indoor low frequency noise levels. They reported the 20 dB limit value would in Maastricht be exceeded in a very large area with many dwellings.

For the Netherlands Commission for Environmental Assessment the second opinion report by Aalborg University was no reason to revise their positive advisory report on the environmental impact assessment for the proposed wind farm.

Nevertheless, on April 24th, 2012 the City Council of Maastricht accepted a motion not to continue the procedure for the zoning plan which would allow the proposed wind turbines. The main reason was lack of support for the wind farm in the City Council and the need to clear up this issue for the concerned citizens of Maastricht.

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