Impact of wind turbine noise in The Netherlands

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Abstract

The Dutch government aims at an increase of wind energy up to 6 000 MW in 2020 by placing new wind turbines on land or offshore. At the same time, the existing noise legislation for wind turbines is being reconsidered. For the purpose of establishing a new noise reception limit value expressed in L_{den}, the impact of wind turbine noise under the given policy targets needs to be explored. For this purpose, the consequences of different reception limit values for the new Dutch noise legislation have been studied, both in terms of effects on the population and regarding sustainable energy policy targets. On the basis of a nation-wide noise map containing all wind turbines in The Netherlands, it is calculated that 3% of the inhabitants of The Netherlands are currently exposed to noise from wind turbines above 28 dB(A) at the façade. Newly established dose-response relationships indicate that about 1500 of these inhabitants are likely to be severely annoyed inside their dwellings. The available space for new wind turbines strongly depends on the noise limit value that will be chosen. This study suggests an outdoor A-weighted reception limit of L_{den} = 45 dB as a trade-off between the need for protection against noise annoyance and the feasibility of national targets for renewable energy.

Keywords: *Environment, legislation, low frequency, noise limit, noise, wind turbine*

Introduction

The aim of this study is to assess proposed new Dutch protective standards for wind turbine noise, both on consequences for inhabitants and feasibility of energy policy targets. The following questions have been considered:

- What is the current impact of wind turbine noise on the Dutch population?
- Can a new legal reception limit value for wind turbine noise be chosen such that the established energy targets can be reached without causing unreasonable negative effects on the population, due to annoyance or complaints on for example low-frequency noise?

Methods

The study is an aggregation of the results of different analyses, for which three different acoustical calculation models have been used.

Access this article online	
Quick Response Code:	Website: www.noiseandhealth.org
	DOI: 10.4103/1463-1741.90331

1. Standard model for nation-wide noise assessment
2. Advanced model to study spectral noise propagation features
3. Parabolic Equation (PE) model to study atmospherical effects on long-distance noise propagation

The way these three models were used in this study is described below.

Method to assess noise exposure and available land space for new wind turbines

The national computation model for industrial noise is used to assess the noise exposure and annoyance due to existing wind turbines and to assess the land space available for new wind turbines under different settings of the legal noise reception limit value. This model is almost identical to the ISO 9613:1996 model that is applied internationally.

The noise impact in the current situation has been calculated using an empirical relationship between acoustical sound power level L_W and electric source power P_{elec} (expressed in kW):[1]

$$L_W(P_{elec}) = 10 \log (P_{elec}) + 71 \text{ dB}$$

The actual electric power (and therefore also the instantaneous acoustical sound power) depends on the local effective wind speed at axis height. For a nation-wide assessment of wind turbine noise expressed in the European noise indicator L_{den}, the following relationship is used:

$$L_{W,den}\ (P_{elec}) = L_W\ (P_{elec}) + 4.2\ \text{dB}$$

This formula is valid for the yearly average wind speed in the geographical center of the country at 80 m axis height, but is assumed in this study to be valid for the whole country. In addition, the subscript "den" indicates a "day," "evening," and "night" weighted 24h-averaging of noise levels. The effect of the L_{den}-weighting function is included here at the source, while it is normally applied at the receiver. The acoustical model then calculates the L_{den} noise map consisting of a grid of 25 × 25 m covering The Netherlands, using $L_{W,den}$ at the position and axis height of each of the 1 955 wind turbines on land. The exposure of the population is determined by combining the noise map with similar (grid) maps containing the number of dwellings.

The acoustical model can also be used to determine the available land space for future wind turbines, given a certain setting of the legal maximum reception level. For this purpose, a reciprocal noise map is calculated. Such a map is obtained by attributing a (constant) acoustical source power to the dwellings, instead of the turbines. At the position of each of the 7 million Dutch dwellings, an imaginary source corresponding to a 2 MW wind turbine (L_W = 104 dB) at 80 m height is fed into the model. The resulting noise map is to be interpreted reciprocally: a new wind turbine can be placed safely in areas with a reciprocal noise level below *X* dB, meaning in reality that the new turbine will not cause more than *X* dB of noise at the nearest façade.

Method to calculate low-frequency noise propagation

An advanced acoustical model is used to find out if it is appropriate to apply the A-weighting function while describing the exposure to and annoyance of wind turbine noise. This exercise is needed as wind turbines are known to generate a relatively large amount of energy in the low-frequency range between 20 and 200 Hz compared with other sources of environmental noise [Figure 1], which could lead to underestimation of annoyance effects.

As the standard Dutch calculation model is not capable of predicting the noise propagation accurately in the lower frequency range, the Harmonoise model has been used.[4] Besides a wide frequency range, this model features a more precise description of ground attenuation effects. Using this model, the propagation of the noise from a Vestas V80 wind turbine was determined over uncompacted, loose ground (turf, grass, loose soil) with representative flow resistivity, σ = 80 kNs/m^4. Source height is 80 m, receiver height is 6 m.

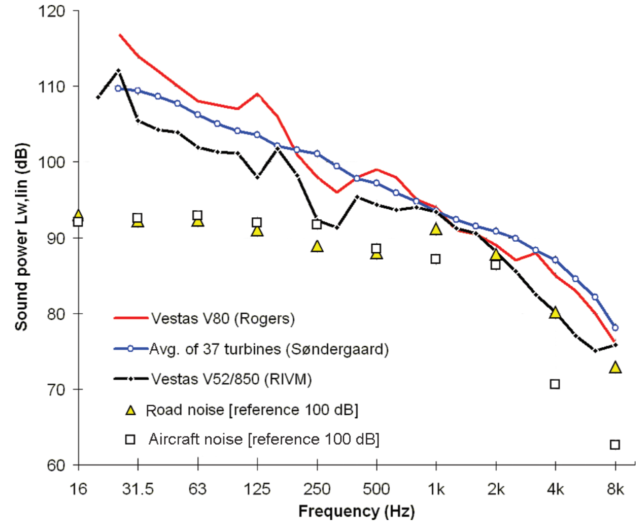

Figure 1: Unweighted source spectra of wind turbines: average of 37 turbines according to Søndergaard *et al.*,[2] a Vestas V80 according to Rogers *et al.*,[3] and a Vestas V52/850 measured by the authors in 2009. Typical spectra for road and aircraft noise are drawn as a reference, normalized at 100 dB SPL

Method to assess temporary impact increase due to (almost) lossless propagation

Wind turbine noise may propagate over large distances (2-5 km), in particular if the propagation takes place over water.[5] Due to atmospherical effects, it is possible that an attenuation of less than the usual 6 dB per distance doubling may result. In order to understand what is going on at large distances, it is necessary to use a propagation model that is able to incorporate such effects. Models based on the PE can handle these properly.

The PE model used is the Monterey-Miami PE (MMPE) model developed for underwater acoustics.[6] In order to get a first impression of the atmospheric influence, we compared an atmosphere with a linear speed profile (1 m/s increase of sound speed per 10 m increase of the height above the surface) to a reference situation with neutral atmosphere. Although in most cases, propagation will take place over solid soil instead of water, cases where industrial sources cause problems in built-up inhabited areas after propagating over relatively large distances over water regularly occur in The Netherlands.

Results

Noise exposure and available land space for new wind turbines

The wind turbine noise map of The Netherlands and the number of dwellings exposed to a certain noise level are shown in Figure 2. At present, 330 dwellings are exposed to a level over 50 dB from wind turbines in The Netherlands. This figure includes privately owned wind turbines (in the yard).

By using a dose-response relationship for wind turbine noise,[7] the calculation results can be converted into percentages of severely annoyed inhabitants [Table 1].

It is roughly estimated that 4 40 000 inhabitants in The Netherlands (3% of the population) are exposed to noise from wind turbines above 29 dB, of which 1 500 are expected to suffer severe annoyance. Almost half of this number occurs within the range 30-40 dB. This is because in a densely populated country as The Netherlands, almost everywhere, urban settlements are within reach of wind turbine noise.

The available space for new wind turbines is assessed by counting the surface area in the reciprocal noise map. Free space increases rapidly with the increasing noise level that is set as legal maximum [Figure 3]. The available free space for new turbines reaches a maximum of 27% of the total area on land at a limit value L_{den} = 60 dB. This is the noise level directly at the foot of an average wind turbine. This maximum is much lower than 100% because of other spatial restrictions, for example due to aviation requirements, nature reserves, and safety aspects in built-up areas.

Table 1: Accumulated number of inhabitants affected and number of severely annoyed inhabitants (indoors)

Exposed by (L_{den})*	Number of inhabitants	Severely annoyed: Number	Severely annoyed: Percentage of total number of annoyed people (1 500)
50 dB or more	740	180	12
47 dB or more	1,810	310	21
45 dB or more	3,110	400	27
40 dB or more	15,250	760	52
29 dB or more	Approx. 4 40 000	Approx. 1 500	100

*Accumulated numbers; each row in the Table includes the numbers in previous rows

Effects of low-frequency noise propagation

A wind turbine operating continuously with a sound power level of L_W = 105 dB causes L_{den} levels of 40 dB and 45 dB at 800 m and 500 m, respectively. To estimate indoor noise spectra, we assumed an insulation value of 10 dB for the average façade attenuation of dwellings within the low-frequency range. This attenuation, to be subtracted from the outdoor level, was based on averaged measurement results.[2,8] Figure 4 gives the resulting linear indoor noise spectra at 800 and 500 m. The other spectra shown in this Figure represent thresholds for audibility (Dutch NSG Guideline[9] and ISO

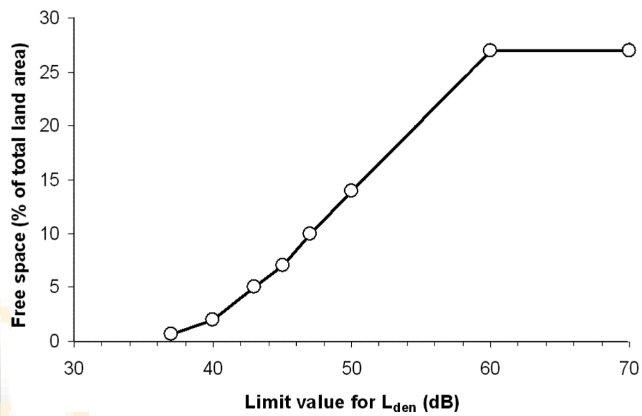

Figure 3: The available space for new wind turbines derived from a reciprocal noise map, as a function of the noise limit value

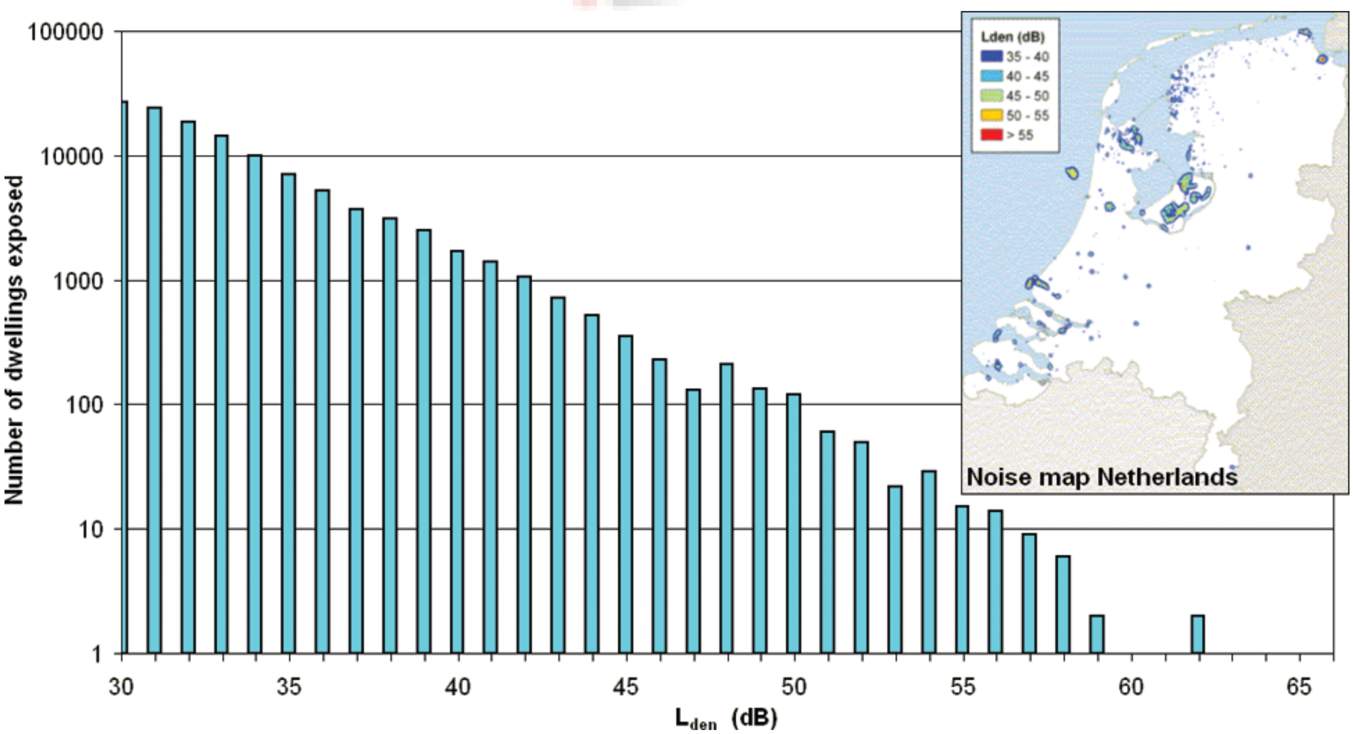

Figure 2: Number of dwellings exposed to a certain L_{den} (outdoors). Inset: Noise map of wind turbines

226[10]) and a threshold for 3 to 10% annoyed (Vercammen[8]). By comparing the calculated wind turbine noise spectra with these thresholds, conclusions about audibility and annoyance of low-frequency noise can be drawn.

Possible temporary impact increase due to lossless propagation

In Figure 5, the noise propagation of a wind turbine at 70 m above the ground is calculated. The average spectrum of 37 turbines according to Søndergaard *et al.*[2] was used as source spectrum. From the results, it is clear that up to 1 km from the source, no large differences occur for the linear speed profile. At larger distances, the noise levels may be between 5 dB lower and 10 dB higher than predicted under neutral conditions. This is in agreement with the results reported elsewhere.[5] This means that under unfavorable atmospheric conditions, here approximated with a linearly increasing speed profile, the sound level around 2 km may be (temporarily) similar to that at 700 m under neutral conditions. Although the model settings need to be validated,

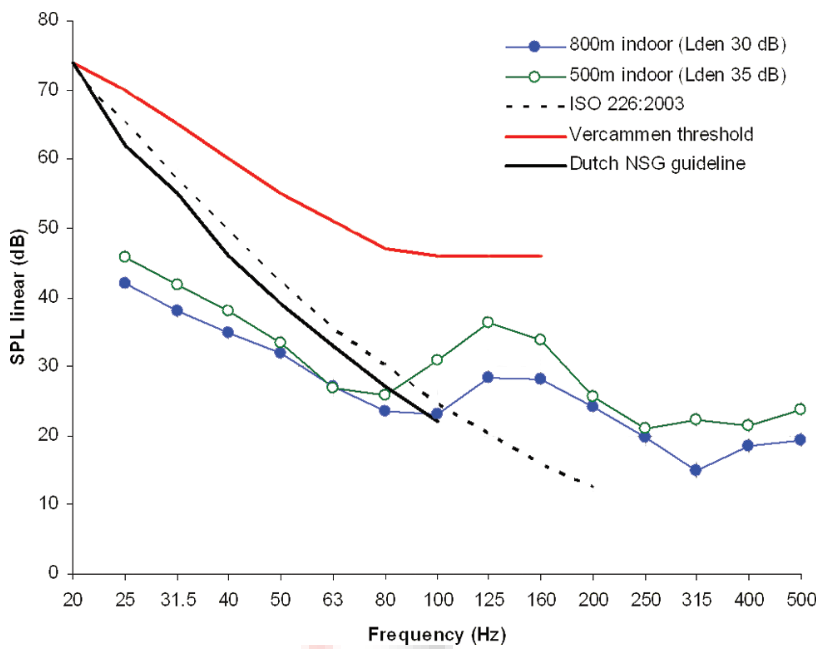

Figure 4: Comparison of linear indoor wind turbine spectra at 500 m (L_{den} outdoor 45 dB) and at 800 m (L_{den} outdoor 40 dB) from a Vestas V80 turbine, with threshold values for annoyance (Vercammen) and audibility (NSG and ISO226)

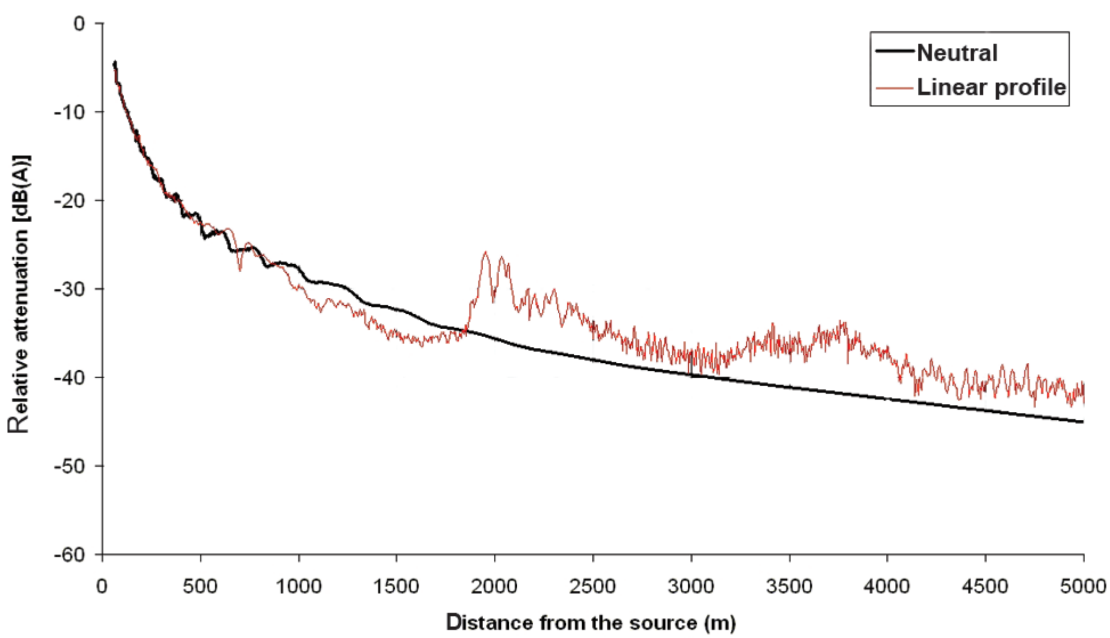

Figure 5: The A-weighted sound level calculated with a PE model as a function of receiver distance for neutral condition (black) and linear speed profile (red), for a wideband wind turbine source spectrum at 70 m above a reflective ground surface

this exercise shows that at large distances, in particular during temperature inversions, higher noise levels can occur than predicted using standard models.

Discussion

Noise exposure and available land space for new wind turbines

Despite the relatively low number of people affected by wind turbine noise compared with road and rail traffic noise, a relatively low noise limit is preferred to prevent severe annoyance. One way of choosing the height of the new noise limit is to balance the percentage of severely annoyed from wind turbine noise to those from other environmental noise sources for which limits were established in the past. For The Netherlands, a socially acceptable percentage of severely annoyed lies around 10%, which can be derived from the existing limits and dose-response functions of railway and road noise.[11] This would result in an acceptable noise reception limit for wind turbines of about 47 to 49 dB. However, the limits for road and railway noise were established in the 1980s as "feasible" limits for a situation in which traffic noise had already grown to a considerable level. This time, we are just at the start of a potential boost of wind energy development. It would therefore be wise to choose a lower noise limit than suggested by what seemed feasible for traffic noise 25 years ago.

By looking at the energy targets for 2020, the feasibility of a limit lower than 47-49 dB can be assessed. From the calculations of available space for wind turbines, approximately 700 km^2 free space (2% of the land) would result from a noise limit of 40 dB. This area corresponds to about 7 GW of wind power on land in The Netherlands. Although this would theoretically be enough for accommodating a policy target of 6 GW in 2020, in practice, many wind energy development plans in (apparently) free areas are rejected due to reasons other than noise. A noise limit of 45 dB seems to be a reasonable compromise between energy targets and environmental quality and would offer approximately 2 500 km^2 of free space and 25 GW of wind power. The percentage of severely annoyed at 45 dB is rated at 5.2% for wind turbine noise,[7] which is well below the 10% that corresponds to the existing road and railway traffic noise limits.[11]

Effects of low-frequency noise propagation

According to the Vercammen threshold, both at 500 and 800 m, severe annoyance effects due to low-frequency noise are unlikely. Both spectra remain well below the threshold curve. However, according to the NSG and ISO 226 threshold, noise will still be audible up to 500 m (L_{den} = 45 dB), in particular near the 100 Hz frequency. At 800 m (L_{den} = 40 dB), the levels up to 125 Hz seem to remain just below audibility. This result implies that people living at 500 m from wind turbines may hear the noise inside their bedrooms, even if the noise level at their façades is below 45 dB (L_{den}).

Possible temporary impact increase due to lossless propagation

The results of the PE calculations suggest that under certain conditions, wind turbines are audible and even may cause annoyance at much further distances than 7 00 m. Particularly, this may occur during temperature inversion and in case of sound propagating over a large reflective surface, e.g., lakes, near shore, or broad rivers. Under these circumstances, standard models for wind turbine noise may underestimate noise levels and it seems advisable to further investigate if such conditions will occur frequently. If so, decision makers should consider additional precautionary measures.

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How to cite this article: Verheijen E, Jabben J, Schreurs E, Smith KB. Impact of wind turbine noise in The Netherlands. Noise Health 2011;13:459-63.

Source of Support: Nil, **Conflict of Interest:** None declared.