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Project WINDFARMperception

Visual and acoustic impact of wind turbine farms on residents

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Specific Support Action, Project no. 044628

Final report

WINDFARMperception

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SUMMARY

This report gives the results of the EU financed study WINDFARMpertception on how residents perceive a wind farm in their living environment as far as sound and sight are concerned. The study includes a postal survey among Dutch residents (n = 725, response rate: 37%) and an assessment of their aural and visual exposure due to wind farms in their vicinity.

Respondents in the survey and calculated exposures
The study group was selected from all residents in the Netherlands within 2.5 km from a wind turbine. As the study aimed to study modern wind farms, wind turbines were selected with an electric capacity of 500 kW or more and one or more turbines within 500 m from the first. Excluded were wind turbines that were erected or replaced in the year preceding the survey. Residents lived in the countryside with or without a busy road close to the turbine(s), or in built-up areas (villages, towns). Excluded were residents in mixed and industrial areas.

The sound level at the residents' dwellings was calculated according to the international ISO standard for sound propagation, the almost identical Dutch legal model and a simple (non spectral) calculation model. The indicative sound level used was the sound level when the wind turbines operate at 8 m/s in daytime -that is: at high, but not maximum power. The size of the turbines was calculated as the viewing angle between the lowest and highest part of the biggest turbine, and also as the fraction of space above the horizon occupied by all wind turbines, both from the perspective of residents' dwellings.

Respondents were exposed to levels of wind turbine sound between 24 and 54 dBA and wind turbines at distances from 17 m to 2.1 km. The (angular) height of the biggest wind turbine ranged from 2 degrees to 79 degrees, with an average value of 10 degrees (the height of a CD box, looking at the front at arm's length). The wind turbines occupied on average 2% of the space above the horizon.

Attitude and economic involvement of respondents
Almost all respondents (92%) were satisfied with their living environment, though many reported changes for the better and changes for the worst. One in two respondents were (very) positive towards wind turbines in general, but only one in five were (very) positive towards their impact on the landscape scenery.

Fourteen percent of the repondents had economic benefits from wind turbines by owning them or having shares in wind turbines or otherwise. They usually lived closer to the wind turbines, were higher educated, less old and hence healthier compared to the other respondents, and they relatively often worked at home. Respondents with economical benefits were less negative to wind turbines in general and their influence on the landscape scenery.

Response to wind turbine sound
The percentage of respondents noticing the sound of wind turbines increased with increasing sound level, ranging from 25% at low sound levels (less than 30 dBA) to 80% and more at

higher sound levels (above 35 dBA). Percentages were the same for those who had benefits and the other respondents.
The percentage of respondents that were annoyed by the sound also increased with sound level up to 40 to 45 dBA and then decreased. Respondents with economic benefits reported almost no annoyance. This in part explains the decrease in annoyance at high sound levels: above 45 dBA, *i.e.* close to wind turbines, the majority of respondents have economical benefits. The percentage of respondents without economic benefits that were rather or very annoyed when outdoors increased from 2% at low levels of wind turbine sound (less than 30 dBA) up to 25% at levels of 40 to 45 dBA.

In general respondents perceived wind turbines as being louder in wind blowing from the turbine to their dwelling (and less loud the other way round), in stronger wind and at night. The majority (75%) of respondents that could hear wind turbines think that swishing or lashing is a correct characterization of the sound. The second most typical characterization was rustling (for 25% of the respondents). Other characterizations were chosen by less than 10% of the respondents.

Respondents were more likely to be annoyed by sound from wind turbines when they noted changes for the worse in their living environment and when they had a more negative view on wind turbines in general or their impact on the landscape scenery.

Health effects
There is no indication that the sound from wind turbines had an effect on respondents' health, except for the interruption of sleep. At high levels of wind turbine sound (more than 45 dBA) interruption of sleep was more likely than at low levels. Higher levels of background sound from road traffic also increased the odds for interrupted sleep.
Annoyance from wind turbine sound was related to difficulties with falling asleep and to higher stress scores. From this study it cannot be concluded whether these health effects are caused by annoyance or *vice versa* or whether both are related to another factor.

Response to other aspects of wind turbines
Respondents were also annoyed by wind turbines in other ways than by sound: between 4% and 13% were rather or very annoyed by vibrations or the movement of rotor blades or their shadows in- or outdoors.

One out of three respondents could not see a wind turbine from their dwelling, especially when living in a built-up area or further away from the turbines. The visibility of wind turbines strongly affected the probability of being annoyed by their sound: when turbines were visible, respondents were far more likely to be annoyed. An unexpected result was that respondents living in a rural area with a main road within 500 m from the wind turbine(s) were less annoyed than respondents living in a built-up area, though the background sound levels from road traffic are on average the same in both area types and one would expect that wind turbines are more readily visible in a rural area.

Recommendations

In this survey sound was the most annoying aspect of wind turbines. From this and previous studies it appears that sound from wind turbines is relatively annoying: at the same sound level it causes more annoyance than sound from air or road traffic. A swishing character is observed by three out of four respondents that can hear the sound and could be one of the factors explaining the annoyance. Sound is therefore an important and negative feature of wind farms and we recommend that, in the planning of wind farms, the negative impact of the sound and sound reduction should be given more attention.

Nevertheless, people that have economical benefits from wind turbines are much less or not at all annoyed, even though they often live closer to wind farms and are exposed to higher sound levels. This lack of annoyance may be the result of several factors: *e.g.* the 'benefitters' have a more positive view on wind farms, they have an actual benefit and they have a measure of control on the turbines. These characteristics may show the way to more acceptance and less annoyance with other residents: residents may be given some benefits and a sense of control too. Discussion of the different views on the landscape, instead of opposition to other views, may help in reaching consensus.

Visibility of wind turbines enhances their potential to cause noise annoyance. When wind turbines are invisible, they cause less annoyance. Perhaps less visibility can also be the result of reducing the visual contrast between turbines and landscape. The possibilities to do this will depend on the landscape type.

The capability of busy road traffic to mask the sound of wind turbines is apparently not straightforward: a higher level of background sound from road traffic indeed reduces the probability of noticing the sound of wind turbines, but it does not have an effect on annoyance from the wind turbines. This may be due to differences between both sounds in pitch, in character (swishing) and in diurnal variation. This issue needs further investigation.

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1. Introduction

There is general public support for sustainable energy, but less support to actual plans to build wind farms as a result of local opposition. In the Netherlands growing public resistance to onshore wind turbines obstructs wind energy development. This opposition is now the main bottle-neck in wind energy development.
There is increasing evidence that the local impact of wind turbines may be more negative than expected. The experience gained in the 1980's and 1990's may not apply to the tall, modern onshore wind turbines with peak electric power outputs up to 3 MW and tower heights of 80 to 100 meters. Research in the Sweden countryside showed that visual impact and noise are factors affecting residents living close to wind turbines [Pedersen *et al* 2004]. In that study it was shown that the noise is more annoying than equally loud road traffic noise and that the annoyance due to noise and to visual impact are interrelated. In a further study [Pedersen *et al* 2006] in other types of environments (now including suburban areas and complex terrain) less annoyance was found. Also, it has been shown that, due to atmospheric conditions assessments of wind turbine noise exposure have been underestimated [Van den Berg 2004, 2005]. As a result both the sound exposure level (in relation to the wind speed) and the character of the sound are not predicted correctly. A British report confirmed this in part by concluding that, in agreement with the recent research, complaints near three UK wind farms can be explained by a modulation of the sound [Hayes McKenzie]. These new findings seem to be related to modern wind turbines and were not established earlier when smaller wind turbines were common.

For modern wind farms the local environmental impact may therefore be significantly different from what was expected from older environmental impact studies. The need to investigate environmental impact is shared by the International Energy Agency (IEA). One of the research priorities identified in the IEA 2005 Wind Energy Annual report is to 'minimize environmental impacts'.
The purpose of this study is to gain insight into the perception of a modern wind farm by residents living nearby such a farm. The objective of the WINDFARMperception project is:
- to provide knowledge on the perception of wind turbines by people living close to wind farms;
- to evaluate human responses to audio and visual exposures from wind turbines and to give insight in possibilities to mitigate the local impact of wind farms.

To investigate the impact of wind farms on residents, the following steps have been followed:
- criteria for dwellings and wind farms to be included in the study were defined;
- relevant data for the selected dwellings and wind turbines were collected;
- residents were asked how they perceived wind farms as part of their living environment;
- the impact relevant for aural and visual perception was calculated;
- the results were analysed.

These steps will be described in detail in the following chapters.

2. Selection of study group

2.1 Study group criteria

The following preliminary criteria were determined from the material available at the start of the project:

- four exposure groups: 25-30, 30-35, 35-40, 40-45 (immission sound level at residence due to wind farm in dBA at 8 m/s 10-m wind speed in a neutral atmosphere).
- three environments: A. quiet countryside, B. countryside with main road, C. built-up area (A and B refer to dispersed residences and small villages, C to large villages and towns).
- equal numbers –if possible- of the population in each exposure group.
- in each of the 4x3 groups (at least) 50 respondents: if so, the results are expected to yield statistically reliable results to be able to determine differences in annoyance between groups.
- response rate at least 30%.

These criteria lead to a study sample of approximately 2000 residents (= 4x3x50/0.3) and an equal number of questionnaires to be sent out.

2.2 Wind turbine selection

A list of all onshore wind turbines in the Netherlands was provided by Wind Service Holland (WSH). The first list gave the status quo of March 1, 2006, the second one of February 26, 2007. From the difference between both lists changes could be determined that had occurred in the year preceding the survey.
As the project aims to study perception around modern wind farms, we have excluded small wind turbines (criterion for ‘small’: less than 500 kW; 679 of all 1735 turbines in March 2006) and single wind turbines (criterion for ‘single’: no other wind turbine within 500 m) from our selection. To be able to obtain results for the three different environments without overlap, wind turbines on large industrial estates and in 'mixed areas' (residential, business and countryside within the same area) were also excluded. This was determined from detailed (1:50 000) topographic maps.

As we wanted to rule out short term, transitory effects, residents living near a wind farm completed within one year before the survey (in fact 14 months: completed after March 2006) were excluded, as were situations with changes in the wind farm (replacing and/or and dismantling older turbines) in the 12 months preceding March 2007.

In figure 2.1 all wind turbines are plotted on a map of the Netherlands. Wind turbines markers overlap in the figure and as a result the dispersed, isolated turbines seem more numerous than the turbines standingcloser together in wind farms. The figure shows that the northern, coastal parts of the Netherlands accommodate most wind turbines.

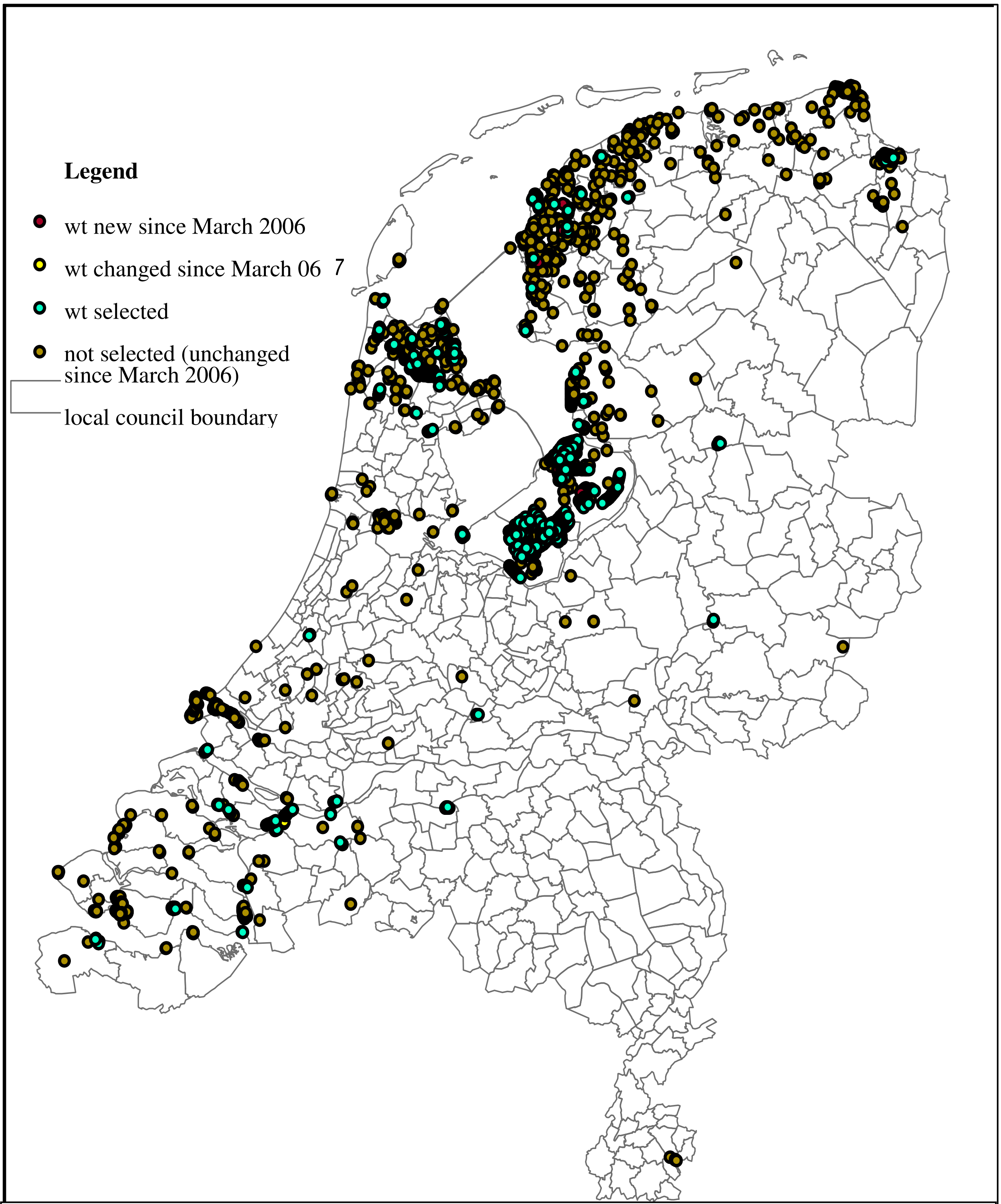

Figure 2.1: geographical overview of all wind turbines in the Netherlands per March 2007; selected for this study are wind turbines ≥ 500 kW, with a similar wind turbine within 500 m, not changed in the year before March 2007, and in either built-up areas or in the countryside

2.3 Postcode selection

The Netherlands are divided in approximately 4000 four-position postcodes, of which approximately 1000 are in urban areas. In a medium sized town (≈ 100 000 inhabitants) there are up to 10 four position postcode areas. In a six position postcode area, with two letters added to four digits –e.g. 1200AB, there are 15 to 20 addresses (dwellings, buildings). The six position postcodes with their geographical coordinates (in the Dutch triangular system) have been downloaded from the KPN phone guide 2007 on CD. The area of one postcode is relatively small in densely populated areas and relatively large in sparsely populated areas. The geographical position of one six position postcode area is therefore not the precise position of addresses in that area.

With the GIS application Arcmap 9.2 postcodes were selected in relation to their distance to the closest wind turbine. Table 2.1 gives the number of six position postcodes in distance classes of 500 m from the nearest (selected) wind turbine. From these postcodes a number were not suitable for the purpose of this project. Therefore postcodes in the following areas have been deleted:

- mixed areas, where different area types are close to a selected turbine and it is unclear in which area type a postcode or address should be classified. These mixed areas were near three towns (Bergen op Zoom, Zutphen and Waalwijk) and consisted of overlapping or very close near-town, countryside, residential and industrial areas.
- industrial estates in three towns (Delfzijl, Culemborg and Zeewolde); an industrial area type is not chosen in this project, because very few people live within the lower distance ranges. Also, other sound from industrial sources is likely to be present that could interfere with the wind farm sound.
- in some cases there were larger villages/small towns in the higher distance ranges of the rural areas. These would increase the study group size of the built-up areas, but only in the lower sound level classes where it is expected the study group is already large enough.
- in the city of Leeuwarden a large number of people live within 2500 m from one of the wind turbines in a business area surrounded by residential areas. Leaving all the postcodes in the study sample would bias the final study group in the built-up area heavily towards this one city. We have therefore selected one suburb (Camminghaburen) and deleted all other Leeuwarden postcodes.

Table 2.1: number of 6-position postcodes per distance range

Distance to nearest wind turbine (m)	*number of 6p postcodes present within range*	*number of 6p postcodes deleted*	*number of 6p postcodes retained*
0-500	148	12	136
500-1000	704	121	583
1000-1500	1557	443	1114
1500-2000	3057	1613	1444
2000-2500	3852	2559	1293

Within 2.5 km from the selected wind turbines we finally had 4570 six position postcodes. For these postcodes we have requested the Land Registry Office (Kadaster) the related addresses from the Dutch address coordinates file (adrescoördinatenbestand Nederland, ACN), only those classified as permanent or holiday residences.

2.4 Address selection

The previous step yielded 50375 addresses with individual x and y coordinates. All addresses were divided into three types of environment:

- rural area (possibly with a major road at least 500 m from a wind turbine): 17923 addresses;
- rural area with a major road within 500 m from a wind turbine: 16826 addresses;
- more densely populated built-up area (in fact parts of four towns): 15626 addresses.

For all these addresses the immission sound level was calculated with a provisional list of wind turbine types (some with estimated sound power levels). The addresses were then classified in 5 dB sound immission level classes (<30, 30-35, 35-40, 40-45, >45 dBA) for each of the three environments (addresses at sound levels < 25 dBA were deleted from the sample). Each class should have approximately 150 respondents (see section 2.1 *Study group criteria* above*)*. In some subgroups there were less than 150 addresses, but in most there were more. In the first case we selected all addresses for the study population, in the second case we took a random sample from all addresses in that subgroup.

As the agencies that enrich addresses with names and telephone numbers only have that information for just over half of all the addresses in the national ACN, we needed to send in more addresses to be enriched than the actual number of names we wanted. In the end we provided 3727 addresses, evenly distributed over subgroups (except when the subgroup was too small). Cendris could provide names and telephone numbers for 2056 of these addresses. From these we used only the 1948 addresses where a private name was given, not when the name was apparently of a business or organization.

Table 2.2: number of addresses per immission sound level range

area type	sound class	all addresses present	addresses selected	addresses needed	% needed/ selected	addresses ordered
1 built-up area						
	>45	11	10	all	100	10
	40 – 45	103	91	all	100	91
	35 – 40	508	404	150	37	330
	30 – 35	2294	1785	150	8	330
	25 – 30	8563	6268	150	2	330
	<= 25	15632	7068	0		0
2 rural + main road						
	>45	124	123	all	100	123
	>40	302	177	150	85	177
	>35	1545	1242	150	12	330
	>30	4024	2478	150	6	330
	>25	9280	5255	150	3	330
	<=25	16835	7554	0		0
3 rural						
	>45	151	150	all	100	150
	>40	358	206	150	73	206
	>35	1151	792	150	19	330
	>30	3713	2561	150	6	330
	>25	9085	5371	150	3	330
	<=25	17624	8538	0		0
all		50073		2024		3727

3. Wind turbine data

3.1 Sources of information

The manufacturer and type of all wind turbines in the Netherlands are part of the information supplied by Wind Service Holland (WSH). As of March 2006, there were 1735 wind turbines in the Netherlands. One year later there were 1839 wind turbines, mostly because the number of large turbines ($P > 2$ MW) had increased. In table 3.1 these are classified in electric power ranges.

Table 3.1: number of wind turbines in 0.5 MW classes

max. electric power P (MW)	number of turbines March 1, 2006	number of turbines February 23, 2007
$P < 0.5$	679	657
$0.5 \leq P < 1$	698	704
$1 \leq P < 1.5$	83	86
$1.5 \leq P < 2$	138	138
$2 \leq P < 2.5$	94	157
$2.5 \leq P$	43	97

There are 78 different types of wind turbines. Most popular are the medium sized Vestas turbines (600, 660, 750, 850 and 900kW; 291 turbines) and the small Lagerweij turbines (75kW and 80kW; 241 turbines). For 30 types 5 turbines or less have been placed, totalling 63 turbines (or 2 turbines per type).

For each type of turbine relevant to this project sound power data had to be obtained. These data are preferably the sound emission level per octave band and the total sound emission level as a function of wind speed. These data were obtained from various sources:

- the archives: those of the Science Shop for Physics (the University of Groningen partner, now discontinued) contained reports from various projects.
- the internet: manufacturers offer technical specifications of their turbines, though detailed sound emission data are often not included.
- local authorities: for licensing of wind farm projects local authorities often request acoustic reports that are, in principle, available to the public. We have contacted local authorities with wind farms to obtain the acoustical data from such reports. These reports form the main source of acoustical data. Most officials have been very helpful and supplied us with the available information.

Consultancies, wind project developers and manufacturers also possess the required data. However, consultancies and developers appeared to consider their reports as confidential information and felt therefore unable to supply the information. Manufacturers Enercon and Vestas were contacted by phone, then communication continued via e-mail because both manufacturers wanted more information about the purpose of our request. After that Vestas ceased communication. Enercon finally declared the project as they understood it was of no value to them, so they would not supply any information. Later we contacted the Dutch office of Enercon that did send us information on two turbine types.

3.2 Sound emission data

The spectral data that have been collected are included in appendix B. In figure 3.1 the available octave band data are plotted[1], as well as the (logarithmically) averaged value, relative to the total sound power level. The figure shows that the spectral form is very similar for all turbines, as Sondergaard has shown for another set of wind turbines [Sondergaard 2007]. Especially at the dominant levels in the middle frequency range (500 – 1000 Hz) all spectral values are in a relatively narrow range, indicating that the spectral signatures of modern wind turbines are very similar.

In appendix C all available total (broad band) sound power levels as a function of 10-m wind speed (in a supposedly neutral atmosphere) have been collected. In figure 2 the sound power levels have been plotted for the two 10-m wind speeds for which most data are available (7 and 8 m/s). If a turbine has several modes to reduce sound production, the mode with no sound reduction at that wind speed is shown.

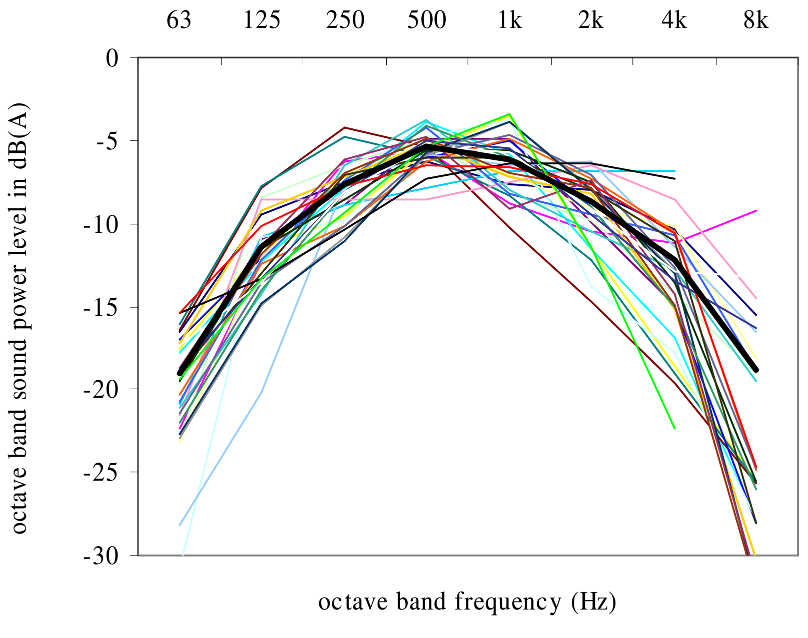

Figure 3.1: A-weighted octave band sound power levels relative to total A-weighted sound power; bold line is average of all octave band data

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[1] except for one spectrum provided by a Dutch consultancy, which is probably incorrect

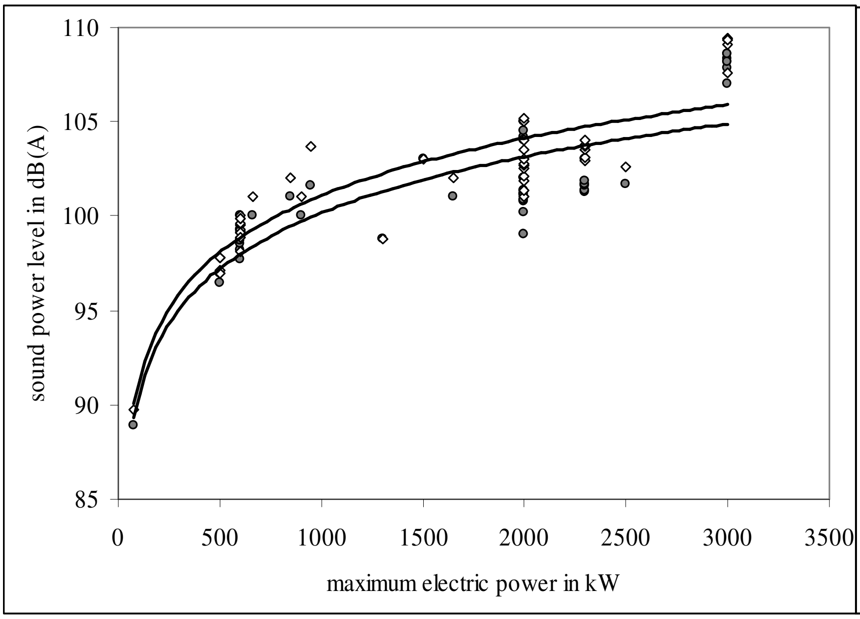

Figure 3.2: total A-weighted sound power level of wind turbines at a wind speed of 7 m/s (dark markers) and 8 m/s (open markers), and best logarithmic fits

The best logarithmic fits to the sound power levels in figure 3.2 are:

- 10-m wind speed = 7 m/s: $L_W = 9.9 \cdot \log(P) + 70.6$ dBA (correlation coefficient 0.84);
- 10-m wind speed = 8 m/s: $L_W = 10.0 \cdot \log(P) + 71.0$ dBA (correlation coefficient 0.89)

The difference between both fits is 0.7 dB over most of the electric power range.

3.3 Wind turbine positions

The list of wind turbines provided by Wind Service Holland (WSH) did not give accurate positions for all wind turbines. In the first stage of the project new and accurate positions as determined by the Netherlands Environmental Assessment Agency (NMP) were available for most wind turbines. For the remaining (few dozens) turbines the positions were determined with Google Earth; the geographical positions in longitude and latitude thus determined were transformed to Dutch coordinates with software provided by the Royal Netherlands Meteorological Institute (KNMI). After delivering the dose calculations to the data base, Wind Service Holland provided us with all accurate positions of all wind turbines as determined by NMP. It is not known what the accuracy is of the positions of the turbines, but it is probably in the order of 1 meter.

4. Dose measures and dose data

4.1 Sound propagation models

For this project three sound propagation models have been used:

- the standard Dutch model as described in the 'Manual to measure and calculate industrial noise' [HMRI], in this report further referred to as 'the Dutch model'.
- the model described in ISO-9613.2 [ISO], representing the international standard for acoustic calculations.
- a simplified model such as used in the New Zealand Standard for Wind Turbine Noise [NZS]; this model was used by Pedersen *et al* in their first study of wind turbine noise annoyance [Pedersen *et al* 2005].

4.1.1 Dutch model

The basic formula for the sound immission per octave band at a receiver point is:

$$L_i = L_{Wr} - \Sigma D$$

where

L_i = immission sound level per octave band

L_{Wr} = source octave band sound power in the direction of the receiver; in practice wind turbines are considered isotropic point sources and therefore have no directivity.

ΣD = Dgeo + Dlucht + Drefl + Dscherm + Dveg + Dterrein + Dbodem + Dhuis, representing all sound attenuation factors as the sound propagates.

Total equivalent sound power level at the receiver is the (logarithmic) sum of all octave band sound power levels from 63 to 8000 Hz.

The first term in ΣD assumes isotropic geometric spreading of the sound at all frequencies: $Dgeo = 10 \cdot \log(4\pi r_i^2)$, where r_i is the (slant) distance between source and receiver.

Dlucht (lucht = air) represents absorption by air: $Dlucht = a_{lu} \cdot r_i$, with a_{lu} the attenuation per unit distance in one octave band. a_{lu} as prescribed by the Dutch Manual is given in table 4.1.

Table 4.1: air absorption according to Dutch sound propagation model

Octave band frequency (Hz)	31	63	125	250	500	1000	2000	4000	8000
a_{lu} (dB/km)	0.02	0.07	0.25	0.76	1.6	2.9	6.2	19	67

Dbodem (bodem = ground) represents the effects from absorption, reflection and scattering due to ground effects and consists of three components: Dbodem = Db,br + Db,mid + Db,ont with:

Db,br = attenuation due to the ground area within a radius of 30·Hbr from the source, where Hbr = source height (hub height in case of a wind turbine; br = bron = source). [1]

Db,ont = attenuation due to the ground area within radius of 30·Hont from the receiver , where Hont is receiver height (height of immission point; ont = ontvanger = receiver).

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[1] The Dutch manual has an error in equations 5.19 and 5.20: r_i should be $>=30h_b$ or $30h_o$ respectively.

Db,mid = attenuation due to the ground area between source and receiver areas or 'middle area'; this is the area between the previous two areas, if this exists; if source and receiver area are contiguous or overlap, Db,mid = 0.

If hub height is taken as 80 m, then the source area has a radius of 30·80 = 2400 m. In that case, for a source – receiver distance less than 2400 m no middle area exists.

The values for the three components depend on the surface's absorptive properties, which is represented by a variable B, ranging from 0 (highly reflective) to 1 (highly absorbent). If part of the area is reflective and the rest absorbent, then B has a value between 0 and 1 and is equal to the percentage of area that is absorbent.

Vegetation may attenuate sound when the vegetation is of sufficient height and thickness to block the view of the source at the location of the receiver. This implies at least several rows of trees located relatively close to the immission point. As most trees in the Netherlands outside forested zones are deciduous and lose their leaves in winter, Dveg is usually taken zero.

ΣD consists of several more components: Drefl (reflection at vertical surfaces), Dscherm (attenuation due to sound screens or obstacles), Dterrein (attenuation due to added absorption over a terrain, such as industrial piping) and Dhuis (attenuation to rows of houses). These components are not calculated in this project (that is: set to zero), as in most cases the receiver points are dwellings in flat and open countryside where there are no obstacles or screens, or built-up or industrial areas. In built-up areas there could be added attenuation due to shielding or reflection of the sound by nearby dwellings, but even here this contribution is relatively small as wind turbines are high sources and the sound in the downwind path, which is assumed to curve downwards in the Dutch model, will propagate over most objects. As a result both Drefl and Dscherm can be taken zero without decreasing accuracy, unless a large object, most likely a building, is located very close to the receiver. To assess this would need very detailed information which was not available and not easy to collect. If a reflector is present, the sound level could be up to 3 dB higher if the reflecting object is large and behind the receiver (as seen from the source). The effect from a nearby screening obstacle can be larger and depends on the obstacle's dimensions, distance and the sound source spectrum. It would always reduce the sound level. Because of this, the sound level at dwellings within built-up areas (not those on the outer edge) is probably overestimated and the real sound level is probably lower than the calculated level.

4.1.2 ISO-9613 model

ISO 9613:1996(E) is an international standard for calculating sound attenuation during propagation outdoors. Its application carries no legal weight in the Netherlands, but it is recognised worldwide. Its basic equation is given by:

$$L_{ft} = L_W + D_c - A$$

Where:

L_{ft} = the equivalent continuous downwind octave-band sound pressure level.

L_W = octave-band sound power level

D_c = directivity correction

A = total attenuation per octave band

Total equivalent sound power level at the receiver is the (logarithmic) sum of all octave band sound power levels from 63 to 80000 Hz.

The terms Lw + Dc are equivalent to the term Lwr in the Dutch method.
A is the equivalent of $\sum D$:
A = Adiv + Aatm + Agr + Abar + Amisc
Here Adiv (divergence) corresponds to Dgeo, Aatm (atmosphere) to Dlucht, Agr (ground) to Dbodem and Abar (barrier) to Dscherm. Drefl is taken as an additional point source in the ISO method. Amisc includes any other miscellaneous terms, like Dveg, Dterrein and Dhuis in the Dutch model.
Variables can thus be defined the same in the ISO and Dutch method, though different symbols may be used. Despite the similarities there are slight differences in the way some terms are calculated.

Adiv is the attenuation due to distance and is the same in all octave bands:

$$\mathrm{Adiv} = 20\cdot\log(d/d_o) + 11$$

where d is the distance between source and receiver, and d_o = 1 m is a reference distance.

Aatm = $\alpha \cdot d/1000$, with α the atmospheric attenuation coefficient, depending on frequency, relative humidity and temperature. A table for α is given in ISO 9613-2:1996(e), on page 5. Though the equation is similar to the one for Dlucht in the Dutch method the coefficients are slightly different. For Dutch conditions we take the average annual temperature as 9 degrees centigrade, relative humidity as 85% and barometric pressure 1015 hPa. Using the ISO 9613 Part 1 calculation method for the atmospheric attenuation coefficient this yields the attenuation coefficients as shown in table 4.2.

Table 4.2: air absorption according to ISO-9613 sound propagation model

Octave band frequency (Hz)	63	125	250	500	1000	2000	4000	8000
α (dB/km)	0.125	0.414	1.02	1.89	3.64	10.0	34.5	122

Attenuation due to ground absorption and reflection is calculated from three components as in the Dutch model: Aatm = As + Ar + Am (source, receiver and middle area, respectively). The equations for As, Ar and Am are slightly different. The variable G is identical to B in the Dutch method.

The term Amisc is composed of attenuation from foliage (Afol), industrial installations (Asite) and housing (Ahous): Amisc = Afol + Asite + Ahous. These terms correspond to Dveg, Dterrein and Dhuis in the Dutch method.
Finally, in ISO 9613 there are terms for barriers and screens as in the Dutch model. These terms, as those in Amisc, are all assumed to be zero.

4.1.3 Simplified model

In contrast with the Dutch and ISO models the simplified model, such as used in the New Zealand Standard 6808, does not use octave band spectra but only uses the total (broad band) sound power level L_W and distance r:

$$L_A = L_W - 8 - 20\cdot\log(r) - 0.005\cdot r$$

Where 8 = $10\cdot\log(2\pi)$, because divergence over half a sphere (*i.e.* above ground) is assumed.

4.1.4 Comparison of models

To be able to compare the differences between the three models, a simple situation is modelled. For this an octave band spectrum from the Vestas V90 is used, shown in table 4.3.

Table 4.3: A-weighted octave band power spectrum of Vestas V90

Octave band frequency	32Hz	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz
Sound emission in dBA	83.6	91.3	95.0	100.5	103.3	102.9	99.5	95.7	95.4

The source is at 90 m height, the receiver at 5 m. It is assumed that all ground is absorbing. Immission sound levels as a function of distance are shown in table 4.4 and figure 4.1. The Dutch and ISO models yield almost similar results, except at great distances due to slightly different air absorption values (which are fixed in the Dutch model, but must be determined from atmospheric conditions in the ISO model). The simplified model overestimates the sound level at small distances due to the assumption of fully reflective ground (+3 dB), and underestimates the level at great distances due to an air absorption value that is too high for the low frequency sound remaining at these distances.

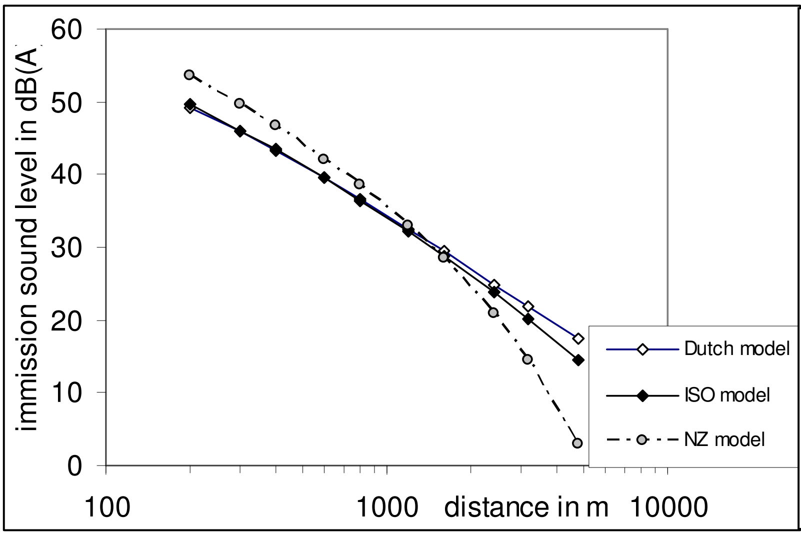


Figure 4.1: sound immission level from a V90 wind turbine over absorbing ground according to three sound propagation models

Table 4.4: A-weighted immission sound spectrum at various distances of Vestas V90 according to three sound propagation models

Distance (m)	200	300	400	600	800	1200	1600	2400	3200	4800
Immission dBA)										
Dutch model	49.3	45.9	43.3	39.5	36.7	32.5	29.4	24.9	21.8	17.4
ISO model	49.6	46.1	43.5	39.5	36.5	32.1	28.8	23.9	20.1	14.4
NZ model	53.6	49.6	46.6	42.0	38.5	33.0	28.5	21.0	14.5	3.0

When the background sound level is 30 dBA or higher, residents living more than 2.5 km away from the nearest turbine will not be able to perceive wind turbine sound or only very faintly. However, the presence of an entire wind turbine park may increase the distance over which sound can be observed. Background sound is dependent on location, so a distant wind farm that is audible at one point may –at the same distance- not be audible elsewhere.

4.2 Sound power levels of turbine types

For a number of turbines the sound spectra could be determined from reported measurements, presented in appendices B and C. For 1182 of the 1846 wind turbines in this project sound power data are available; 291 of these have a maximum electric power less than 500 kW. For 664 wind turbines in this project no sound power data are available; 358 of these have a maximum electric power less than 500 kW.

From the results presented in figures 3.1 and 3.2 it follows that sound power spectra are similar for all turbines, and that total sound power depends on electric power production. Therefore, for the 664 wind turbines where no sound power data were available, we have used the sound power data of a known type of the same electric power.

The sound power was used as given for a wind speed of 8 m/s at 10 m height in standard atmospheric conditions. The result is a list of turbine types given in appendix D, where types with sound power data from reported sources are numbered 1 through 28, and types with sound power data determined from other types are numbered r1 through r28 (coincidentally these are also 28 types).

4.3 Sound dose

4.3.1 Input parameters

For all respondents the immission sound level was calculated from the sound power level at high electric power according to all three sound propagation models (Dutch, ISO and NZS model). If different operational modes were present, the highest (loudest) mode was used. The sound power data used are those given in appendix D.

The following values were used as input of the calculation models:

- sound power spectrum and source height: from appendix D.
- sound absorption in air: from tables 6 and 7.
- receiver height: 5 m.
- ground absorption (all areas): 100% (B = G = 1).

Although addresses are selected within 2.5 km from all wind turbines with a minimum electric power of 500 kW and with another turbine present within 500 m, and where no changes have occurred in the year preceding the survey, the sound levels have been calculated due to all turbines within 2.5 km of each address. This therefore includes the sound of smaller wind turbines (< 500 kW) in the area of the receiver.

In figure 4.2 the individual calculated levels according to the Dutch and the simplified model are plotted versus those of the ISO model. The Dutch and ISO models are highly correlated and yield almost identical results, as could be expected from the similarities between both models. The difference in results between the ISO and Dutch model vary from -0.8 to 1.4 dB, the average difference is 0.3 dB. The difference in results between the ISO and simplified model vary from -4.4 to 1.8 dB, the average difference is -0.8 dB.

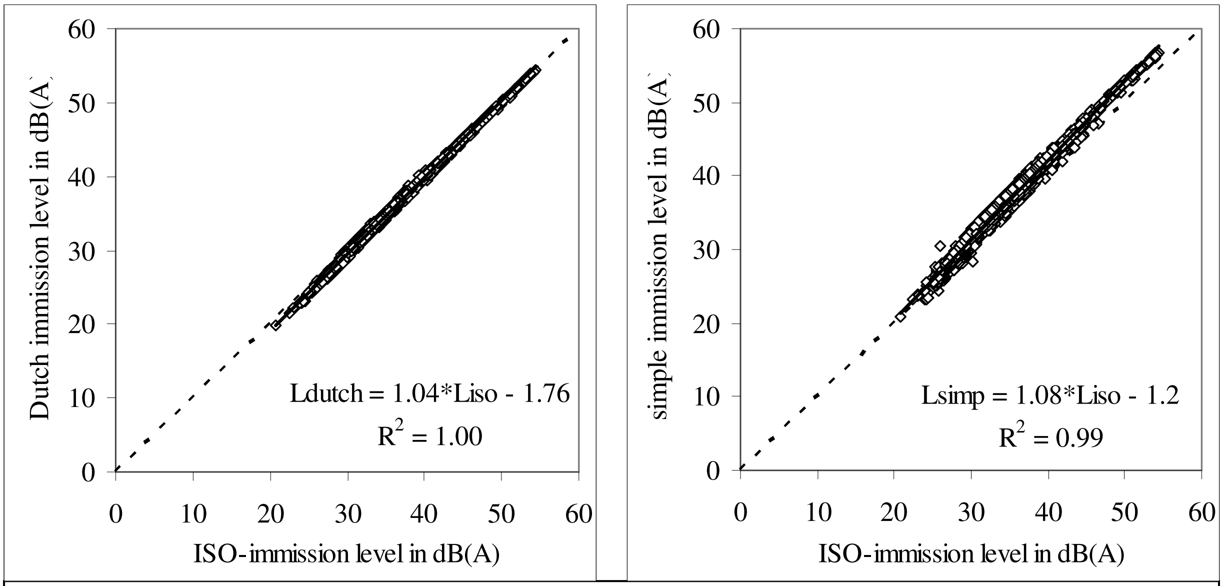


Figure 4.2: maximum immission sound levels according to the Dutch (left) and simplified (right) models plotted versus the ISO-9613 model

In figure 4.3 the sound immission levels according to the ISO-9613 propagation model are plotted versus distance to the nearest wind turbine. Both parameters are highly correlated, considering the variety in wind turbine sizes and wind farm lay-outs.

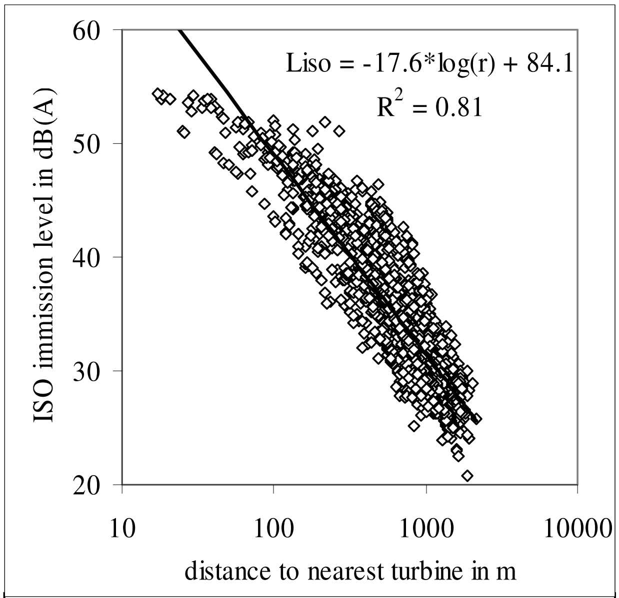


Figure 4.3: maximum immission sound level according to ISO-9613 model versus distance to nearest wind turbine

4.3.2 L$_{\text{den}}$

The result of the sound dose calculations is the total A-weighted sound immission level due to all wind turbines close to a receiver and the turbines operating at high electric power. This can be converted to a day-evening-night averaged sound level or L_{den}., which is now the common noise exposure metric in the European Union. The procedure for this will be presented in a paper presented at Acoustics'08 [Van den Berg 2008], calculating Lden for an inland an coastal location, 3 hub heights (60, 80 and 100 m) and three types/modes of wind turbines. The result is that the sound power $L_{W,den}$, to be used as the characteristic sound power to calculate L_{den}, can be expressed relative to the sound power level at an 8 m/s 10-m wind speed (neutral atmosphere): $L_{W,den} – L_{W,8m/s} = 4.7 \pm 1.5$ dB.

4.3.3 Accuracy of calculated sound levels

ISO-9613 has been shown to be an accurate model for the prediction of (maximum) wind turbine immission sound levels, except sometimes in terrain with steep gradients [see, *e.g.*, ETSU-W13, Bullmore].

For the dose calculations two assumptions have been made that may not apply at all respondents, *viz.* a receiver height of 5 m and a fully absorbent ground. Also it was assumed that there is no reflection (other than from the ground) or shielding of the sound from a wind turbine, because respondents in the countryside live in farms or detached houses. In built-up areas this may not be true, but will seldom lead to very different results (see final paragraph in section 4.1.1).

A receiver height of 5 m is used because usually bedrooms are on the first floor and the night time level is the most restrictive limit and often the highest level. For ‘ear height’ on the first floor a height of 5m is assumed in the Netherlands. If residents stay on the ground floor, as is more usual when the bedroom is on the ground floor and in day time, a receiver height of 2 m is more realistic. Using this height yields sound immission levels that are 0.1 dB lower than those calculated at 5 m.

For a receiver height of 5 m, the receiver area stretches 150 m towards the sound source. In the countryside all or most of this area will be soft (bare or covered with vegetation) ground. If the entire stretch would be paved or consist of a water surface, it would reflect sound which would yield higher sound levels at the receiver. Comparison of all calculated results with Grec = 1 relative to Grec = 0 shows that with a fully reflective receiver area the immission sound level is 1.4 dB higher than the level used in this study for the absorbent ground.

4.4 Visual dose

There is no generally accepted measure to determine the visual impact of a wind farm (or in fact the visual impact of other objects).

4.4.1 Vertical angle

Pedersen *et al* [2007] used the vertical angle of a wind turbine as a measure of impact, defined as the angle between the horizontal at the receiver and the line between the receiver and the turbine hub. In hilly area, if a turbine is situated at an elevated position, this includes the angle between the horizontal and a line from the receiver to the base of the turbine. This implies that a 50 m high wind turbine on a 200 m hill at 500 m distance has the same impact as a 100 m high turbine at ground level at 250 m distance. It is not obvious this would indeed have the same objective impact. However, in flat terrain elevation is nil and the vertical angle only depends on distance and turbine height.

When several wind turbines are visible, the vertical angle is the maximum value of the individual vertical angles.

4.4.2 Fraction of field of view

From a planning point of view “the two principal criteria determining significance [of effects] are the scale or magnitude of effect and the environmental sensitivity of the location or receptor” [Landscape Guidelines]. Visual impact of an object thus depends on the size of the object in the field of view and the appropriateness of the object in its environment, and thus depends on a quantity (relative size) and a quality (appropriateness). This quality depends on the contrast between the object and its environment (*e.g.* a highly technical object in a natural landscape, or a yellow building between brown brick buildings) and the appreciation of the object in its environment (depending on purpose, material, perceived beauty, etc.), and must be determined from people's judgments. In fact, this project will yield the assessment of this quality by the respondents.

The quantity is the size of an object relative to the total field of view. It can be defined as the size of the object area normal to the receiver, divided by the area of half a sphere with a radius equal to the distance between receiver and object. In this study, as illustrated in figure 4.4, the relative size is the area 2R(R+H) divided by the area $2\pi r^2$ of the half sphere with radius r. The quantifiable part of the visual impact is thus the fraction of the total field of view (= half sphere above the horizon) covered by a schematized turbine. This is equal to twice the space angle as defined in mathematics (twice because in mathematics the area is relative to the entire sphere). Replacing a wind turbine by a rectangle seems a very schematic approximation, but the rectangle area is highly correlated to the actual size of the rotor and/or the rotor + mast because wind turbine diameter and hub height are highly correlated (best fit: diameter = 0.95*hub height, correlation coefficient = 0.91). The calculation is valid for a relative size <<1, because then the rectangle area projected on the curved sphere can be approximated with plane geometry. For bigger values the relative size will be overestimated by the calculation used.

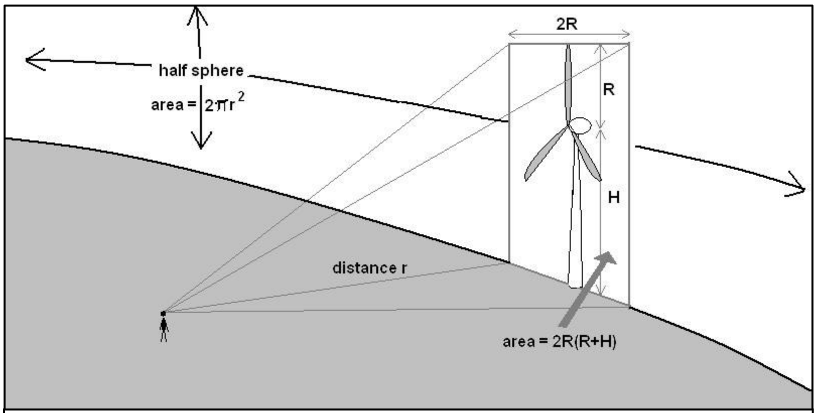


Figure 4.4: sketch of schematized turbine size relative to total field of view

For several wind turbines the (total) relative size is the sum of the individual relative sizes. In the text below the (total) relative size will also be referred to as the percentage of view.

In figure 4.5 the relation between the total relative size and the maximum vertical angle of all wind turbines within 2.5 km of a receiver is plotted for all respondents. At high angles, the divergence from the best fit to all data points is probably due to overestimating the relative size when a wind turbine is very close to the receiver.

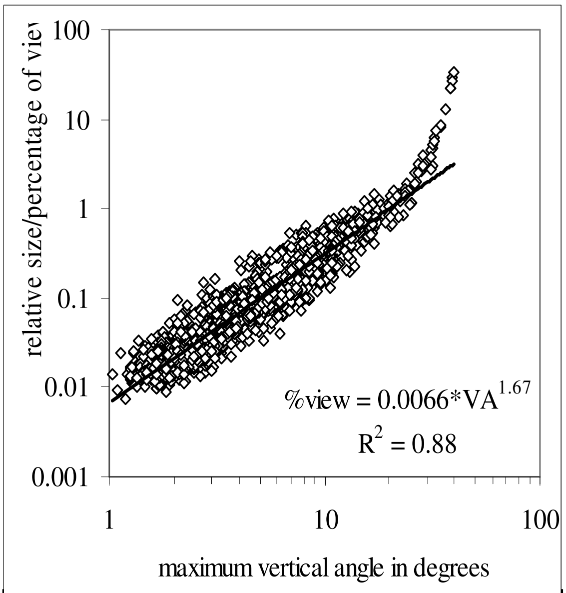


Figure 4.5: relation between visual impact parameters

In figure 4.6 both visual impact parameters for al respondents are plotted versus the distance between each receiver and the nearest wind turbine. Again the parameters are highly correlated.

4.5 Receiver – wind turbine distance

The distance between a wind turbine and a receiver is an attractive dose measure as it would constitute a very simple measure of impact. Because visual as well as aural dose have been shown to correlate well with distance, perhaps distance can be used as a single measure for impact. When more wind turbines are present, the dose measure is the distance from the receiver to the nearest turbine.

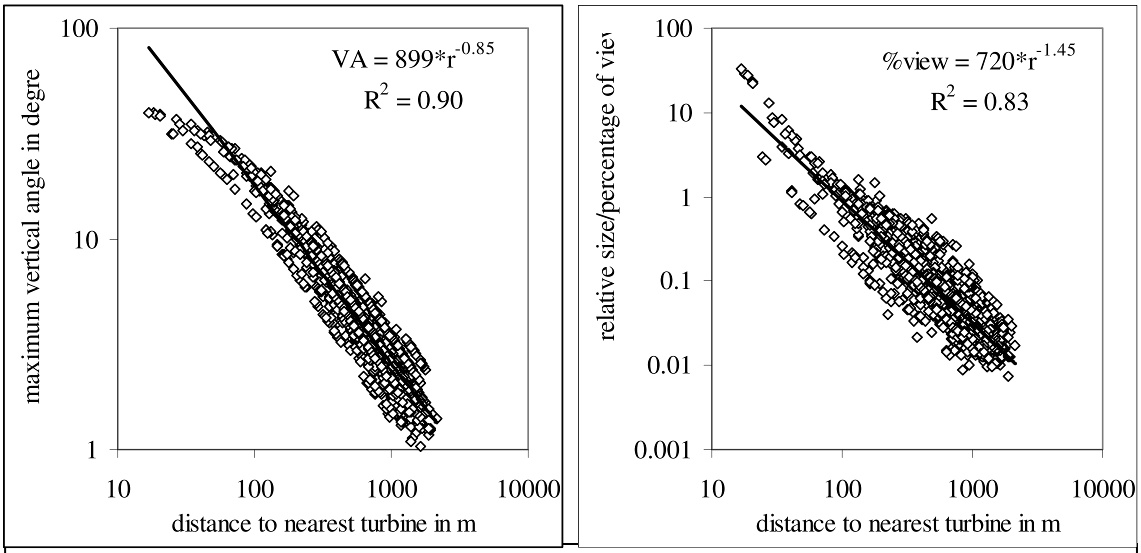
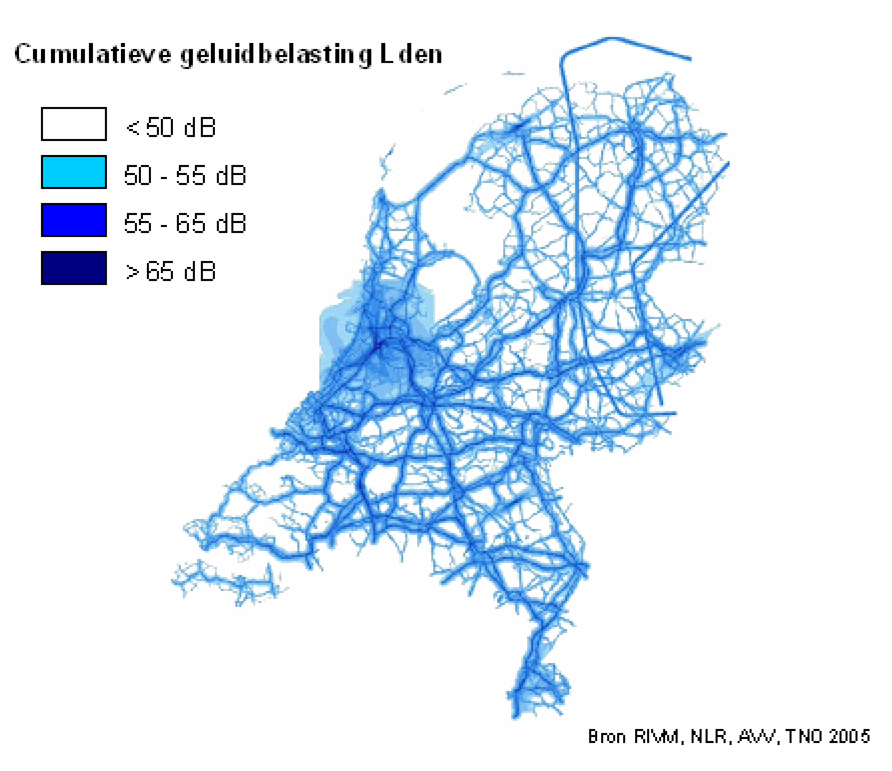


Figure 4.6: relation between visual impact parameters (left: maximum vertical angle, right: relative size/percentage of view) and distance to nearest wind turbine

4.6 Background transportation sound levels

The study sample originally was divided in three categories: those living in built-up areas in towns, and those living in the countryside, either with or without a major road close (< 500 m) to at least one wind turbine. The purpose of this distinction (the presence of the road in an otherwise similar environment) was to investigate the effect of possible masking of wind turbine sound by other continuous sound, notably road traffic sound. However, in a later stage we contacted the Dutch National Institute for Public Health and the Environment (RIVM) and they were so kind to supply us with their database of transportation sound levels of the Netherlands. The database contains calculated day-evening-night sound immission levels (L_{den}) due to road, air and rail traffic for a 25 m by 25 m grid over the entire country (see figure 4.7). The levels are based on traffic volumes in 2002. Mopeds, motor bicycles, and local traffic on minor roads are not included in the road traffic sound level, and overflying (*i.e.* no taking of or landing) aircraft are not included in the aircraft sound level.

For (nearly) all respondents there is no railroad or airport nearby, so road traffic will dominate the Lden value. For each respondent the value at the nearest grid point has been used.



Bron RIVM, NLR, AVV, TNO 2005

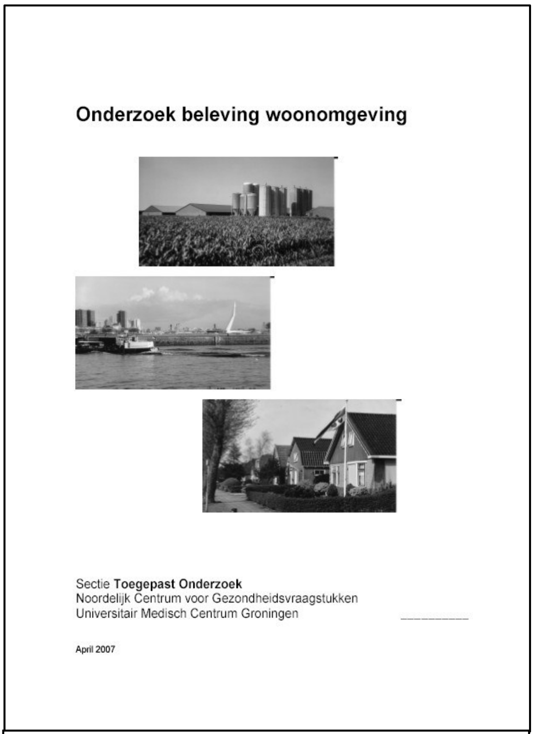
Figure 4.7: 'background' transportation sound due to road, air and rail traffic

5. Survey preparation and implementation

5.1 Questionnaire preparation and handling

The base material for the Dutch questionnaire in this project was the Swedish questionnaire used by Pedersen *et al* [Pedersen *et al* .2005, 2007]. This was translated from Swedish into English by Pedersen, then translated by the Dutch partners into Dutch. All the important questions pertaining to dose and response were kept, those addressing coping strategies were left out, and questions regarding health and the environment were added. Part of the questions measuring 'perceived health' consisted of a validated instrument: the General Health Questionnaire (GHQ). Quality of life was measured with ordinal scales ranking from 10 (best possible quality of life) to 1 (worst possible quality of life). Also questions about other environmental factors were added to obtain better masking of the main topic (questions about road traffic were made equally important in the questionnaire) and to be able to make more comparisons to other environmental factors.

After carefully checking the precise wording and lay out the questions were translated back into English and checked by Pedersen. Finally the questionnaire was made definite and 2000 copies were printed. The questionnaire's cover (figure 5.1) shows the title "Onderzoek beleving woonomgeving" ("Study of the perception of the living environment") and as sender –again in Dutch- the Section Applied Research of the Northern Center for Healthcare Research from the Unversity Medical Center Groningen (UMCG)[1]. The English translation is given in appendix A.



Onderzoek beleving woonomgeving

Sectie **Toegepast Onderzoek**
Noordelijk Centrum voor Gezondheidsvraagstukken
Universitair Medisch Centrum Groningen

April 2007

Figure 5.1: front of questionnaire (original is size A4)

Questionnaires were sent in the second half of April 2007, reminders were sent to all non-responding candidates (1475) three weeks after sending the questionnaires. In order to stimulate the response it was announced that every hundredth respondent received a gift certificate of € 25. Respondents that were interested in receiving the result of the study could leave a small note in the prepaid envelope which was enclosed to return the questionnaires, or – if they were connected to the internet – they could supply us with their e-mail address. Two hundred sixty (36%) of the respondents did so.

The survey database was developed in Clipper.

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[1] now: section Applied Research/SHARE of UMCG

5.2 Response rate

Of the study sample (n = 1948), 37% (n = 725) answered and sent back the questionnaire. The final response rate was 37%, higher than the expected response rate of 30%. The response rate was of the same magnitude in all 5-dBA intervals of immission sound levels due to wind turbine noise (table 5.1). The response rates in intervals of high immission levels were not higher than the responses rates in intervals of low immission levels. Biases in the forthcoming analyses due to a higher amount of people exposed to high levels of sound from wind turbines responding to the questionnaire could therefore be excluded.

Table 5.1: response rate related to immission levels

	Immission intervals, ISO, dBA					**Total**
	<30	**30-35**	**35-40**	**40-45**	**>45**	
Study sample, n	491	589	421	250	197	1948
Respondents, n	185	219	162	94	65	725
Response rate, %	38	37	38	38	33	37

5.3 Non-respondent analysis

A non-response analysis has been carried out, based on the questions 26 and 27 of the questionnaire, which can be regarded as ‘core questions’ of our study. These questions dealt with the level of annoyance respondents experienced from the sound of wind turbines *outside* (question 26) and *inside* (question 27) their dwelling. On both questions respondents could mark a figure between 0 and 10, which corresponded closest to their perceived annoyance. The higher the figure marked, the more they declared to be annoyed. The questions 26 and 27 were sent as a separate questionnaire to a randomly chosen sub sample of 200 non-respondents. Ninety five of the non-respondents filled out and sent back these small questionnaires. The mean score on both questions was compared between the responders (n = 725) on the one hand and these 95 ‘responding non-responders’ on the other, using independent t-tests (for the two main questions: t = -0.82, p = 0.412 and t = -0.74 and p = 0.458). No statistical significant differences in annoyance between the two groups could be found, meaning that there is no evidence that respondents form a selective group with regard to annoyance within our sample of all approached people living in the neighbourhood of wind turbines (n = 1948).

5.4 Validity and reliability

Analyses of the results showed a high validity for the sampling and the classification of areas in the study. Respondents living in built-up areas or areas with a main road were exposed to statistically significant higher levels of Lden, i.e. background sound levels mainly due to road traffic, than respondents in rural areas without a main road just as expected (ANOVA, post hoc test LSD: Built-up vs. rural area with no main road, p<0.001; rural area with main road vs. rural with no main road, p<0.001).

The questionnaire had a high internal reliability for measurements of response to wind turbine sound. Five questions in the questionnaire assessed response to wind turbine noise in different wording and with different scales: response to wind turbine noise as an exposure among other exposures outdoors (question 10) and indoors (question 11), response to sound from the rotor blades (question 22) and ratings on an 11-point scale of response to wind turbine sound outdoors (question 26) and indoors (question 27). The questions showed high internal consistency (Cronbach's alpha = 0.871).

6. Analysis model and method

6.1 Dose-response model

The objectives of this study were to provide knowledge on the perception of wind turbines by people living in the vicinity of wind farms, to evaluate human responses to aural and visual exposure from wind turbines and to provide data that could be used to avoid their possible negative impacts.

A theoretical model developed to explain the relation between exposure and response, based on the results from previous studies of community noise and specifically wind turbine noise, was used as a base for the present study (figure 6.1). Exposures from wind turbines are assumed to generate a response among the exposed population. This response could lead to adverse effects on health and well-being, but several factors may moderate the outcomes of the exposures. These factors could be physical, i.e. related to the living conditions and the environment. They could also be individual, i.e. related to the receiver of the exposure.

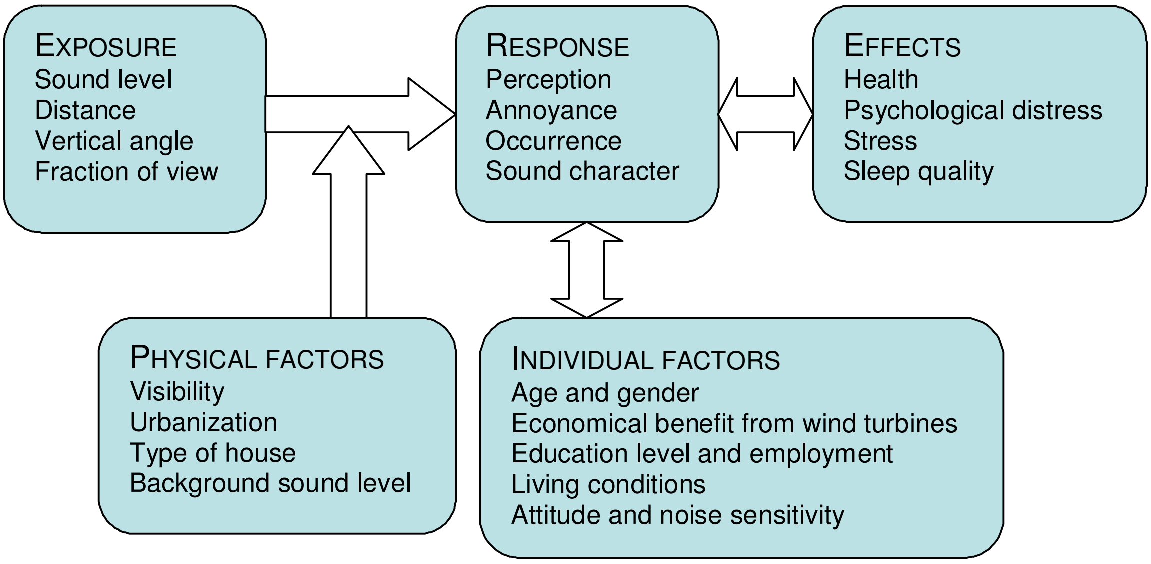


Figure 6.1: theoretical model of the relation between exposure and response

6.2 Method

6.2.1 Exposure measurements

Four physical exposures from wind turbines were estimated for each respondent in the study. As described in Chapter 4, sound pressure levels (in dBA) of wind turbine sound were calculated as the levels outside the dwelling of the respondent. Distance (in meters) was measured as the distance between the respondent and the nearest wind turbine. Vertical angle (in degrees) was the largest of all angles between a horizontal line and the line from a respondent to the highest tips of the rotor blades of the wind turbines in the area. Fraction of view (as a percentage) was the proportion of a half sphere above the horizon that was covered by (schematized) wind turbines, as seen from the dwelling of the respondent.

6.2.2 Response measurements

Response to wind turbines and subjective health status was measured in a questionnaire. The questionnaire was previously developed and used in the Swedish studies, but modified to suit conditions in the Netherlands and enlarged with the General Health Questionnaire (GHQ) and some questions probing more detail as described in chapter 5 *Survey preparation and implementation*. The questionnaire comprised questions on response to several sources of possible disturbance in the living area, including wind turbines.

6.2.3 Statistical analyses

The measurements obtained had different characters that required different statistical methods. Exposures, for example sound level, were measured on continuous scales, as were some of the individual factors, for example the age of the respondents. Also scores derived from several items in the questionnaire could be viewed upon as continuous scales. Continuous scales are in the results presented with mean values. The standard deviation (SD) gives an indication of the spreading of the variable; a large standard deviation indicates a large spread and vice versa. The Student's t-test was used to test if there was a statistically significant difference in means and distribution between two groups. If more than two groups were tested, the ANOVA and the post-hoc test LSD were used for the same purpose. In all tests a p-value below 0.05 implies that an observed difference between the groups is likely to be a real difference, not one due to chance (although there is a 5% probability that it is a coincidence).

Most variables in the study were not measured with continuous scales, but with ordinal scales that have some kind of order by classification, even though they are not regular scales with the same increment between successive scale points. For example: response was measured from "do not notice" to "very annoyed". The results are presented as proportions of respondents that reported one or more of the points, for example the proportion of respondents annoyed by wind turbine sound. Confidence intervals (CI) of 95% were calculated in accordance with Altman *et al* [Altman 2005]. A confidence interval can be interpreted as the interval wherein the "true" proportion very probably (with 95% certainty) would lie. For these ordinal scales the differences between groups were tested with the Mann-Whitney U-test. Again for this test, p-values below 0.05 indicate a difference between groups.

Relationships between two or more variables were tested with Pearson's product-moment correlation, with Spearman's rank-order correlation and with binary logistic regression. Pearson's (two continuous variables) and Spearman's (if at least one variable was ordinal) test of correlation are useful when the agreement between two variables is of interest. The outcome is a value between 0 and 1; the closer to 1, the higher the correlation is or the better the two variables agree with one another. Binary logistic regression is a more advanced test in that several variables can be tested at the same time. First a model is constructed that explains the relationship between a dependent variable that is to be tested and independent variables that are supposedly related to the dependent variable, and with variables that may influence the relationship (the ‘variables adjusted for’). In a binary logistic regression the dependent variable can only have two values. If it has more than two values, it is dichotomized. For example, response to wind turbine noise can be dichotomized into "do not notice" (point 1) versus "notice" (points 2 through 5) when exploring perception, and into "not annoyed" (point/slightly 1 through 3) versus "rather/very annoyed" (points 4 through 5) when exploring annoyance. The outcome of the test is the odds ratio (OR) with a 95% CI. An OR below 1.0 with a 95% CI not including 1.0 indicates that there is a negative correlation between the dependent and the independent variables. An OR above 1.0 with a 95% CI not including 1.0 indicates that there is a positive correlation between the variables; i.e. the dependent variable will increase if the independent variable increases. If the CI includes 1.0 there is no (significant) correlation. Finally, the Hosmer and Lemeshow test is used to test the agreement between the model tested with the binary logistic regression and the data. A p-value *above* 0.5 indicates that the model and the data are in agreement. When the p-value is below 0.05, the model does not fit the data.

Factor analyses (principal components analyses; Varimax) were carried out when a factor was measured with several items. The factor analysis finds a pattern in the measurement from which a score can be calculated. This score has a mean value of 0.0 and a SD of 1.0. Cronbach’s alpha was used to test the interval consistency of the items within a factor. The factor scores were treated as values on a continuous scale and the association with other variables were therefore tested in linear regression models. The outcome of the linear regression is presented with the scale dependent coefficients of the variables in the model (B) but also with standardized coefficients (Beta) that can be compared to other standardized coefficients.

Psychological distress was measured with the validated protocol General Health Questionnaire (12-item version) on a 4-point scale from 0 to 3. Six of the items were negative statements and six were positive statements. The replies were coded so that a high score always meant a higher load of psychological distress than a low score. The scale was dichotomized. For negative items scale points 1-3 were classified as sign of distress. For positive items, scale points 2 – 3 (reversed scale) were classified as sign of distress. The ratings from the dichotomized items were added into a GHQ-score, with a 13-point scale from 0 to 12. The GHQ-score was treated as a continuous scale.

Table 6.1 lists the abbreviations that are used in the presentation of the results in te next chapter.

Tabel 6.1: abbreviations used in the presentation of results

alpha	A value between 0.0 and 1.0 that indicates the consistency of two or more variables. A value close to 1.0 indicates high consistency.
B	Unstandardized regression coefficient for a variable in a multiple linear regression. Scale dependent.
Beta	Standardized regression coefficient for a variable in a multiple linear regression. Beta ranges from 0.0 to 1.0. The value could be compared to Beta of other variables within the same multiple regression (a higher Beta implies a higher impact on the dependent variable), but not between separate regressions.
H-L test	Hosmer-Lemeshow test provides a value between 0.0 and 1.0. A low value (<0.05) indicates that the modelled regression do not fit the data.
n	Number of respondents.
OR	Odds ratio. The ratio between the odds for the dependent variable to occur if the independent variable is 1 (or "yes", or one scale point higher) and the odds for the dependent variable not to occur if the independent variable is 0 (or "no", or one scale point lower). A value below 1.0, with a confidence interval with both values below 1.0, indicates that the independent variable lower the odds for the dependent variable to occur and vice versa.
p	The probability that a tested hypothesis is true. The hypothesis is often "there is no difference between the groups" or "there is no correlation between two variables". If the p-value is less than 0.05, i.e. the probability that the hypothesis is true is less than 5%, it will be interpreted as there *is* a difference between the groups or that there *is* a correlation.
r	Correlation coefficient derived with Pearson's product-moment correlation. The values range from 0.0 to 1.0; a high value indicates a strong correlation.
r_s	Correlation coefficient derived with Spearman's rank-order correlation. The values range from 0.0 to 1.0; a high value indicates a strong correlation.
t	The outcome of a Student's t-test that tests if two samples have the same distribution and the outcome of an ANOVA that tests of three groups or more have the same distribution; with other words, if there is a difference between groups. A high value indicates that there is a difference between the groups.
Z_{MWU}	The outcome of a Mann-Whitney U-test which tests if there is a difference between two groups. A high value indicates that there is a difference.
95% CI	Confidence interval of 95%. A range of values within there is a 95% probability of the true value occurring.

7. Results

In this chapter the results of the study will be given in a sequence based on the model presented in section 6.1 *Dose-response model*. Each of the components of the model will be analyzed in a separate section (in each section one of the 'boxes' of figure 6.1 is repeated). Then the relation between components will be investigated.

7.1 Exposures from wind turbines

EXPOSURE
Sound level
Distance
Vertical angle
Fraction of view

The mean values of the four exposure values for the respondents in the study are shown in table 7.1.

Table 7.1: mean value and distribution of sound levels, distance, vertical angle and fraction of view for all respondents

n = 725	Unit	Mean (SD)	Minimum	Maximum
SPL	dBA	35.1 (6.41)	23.8	54.4
Distance	meter	741 (408)	17	2138
Vertical angle	degree	10.4 (10.3)	2.2	79.0
Fraction of view	%	2.0 (13.2)	0.1	263.0

All exposure variables depend on the distance between the wind turbines and the dwelling of the respondents. They were therefore highly correlated (table 7.2). That means that it is difficult to distinguish between the influences of one of the exposure variables in comparison to the influence of another of the exposure variables. The sound level will in this report be assumed to be the most relevant exposure variable for noise annoyance and is therefore used in statistical tests when exploring the relationship between exposure and response.

Table 7.2: correlations between distance, vertical angle, fraction of view and sound levels for all respondents

n=725	Distance		Vertical angle		Fraction of view	
	r_s	p	r_s	p	r_s	p
Distance	---					
Vertical angle	-0.927	<0.001				
Fraction of view	-0.860	<0.001	0.916	<0.001		
SPL	-0.893	<0.001	0.924	<0.001	0.973	<0.001

The respondents were divided into five groups based on the levels of sound from wind turbines outside their dwelling. The number of respondents was smaller in the groups with higher levels of sound than in groups with lower levels (table 7.3). Only 65 respondents were exposed to more than 45 dBA, which means that the results of this study will be less certain for respondents exposed to high levels of sound than for those exposed to lower levels.

Table 7.3: number of respondents at each 5 dBA-interval of sound levels.

n=725	Sound pressure levels, dBA				
	<30	30-35	35-40	40-45	>45
Number of respondents	185	219	162	94	65

7.2 Physical factors

PHYSICAL FACTORS
Visibility
Urbanization
Type of house
Background sound level

7.2.1 Visibility

Of the respondents, 68% could see at least one wind turbine from their dwelling, while 32% could not. Almost all respondents in groups exposed to 35 dBA or more could see wind turbines from outside or inside their homes (table 7.4), the number of visible wind turbines ranging from one to more than 75.

Table 7.4: proportion of respondents that could see at least one wind turbine from their dwelling, in relation to levels of wind turbine sound

n=715	Sound pressure levels, dBA					Total
	<30	30-35	35-40	40-45	>45	
Visibility, %						
Wind turbine visible	35	60	90	89	100	68
Wind turbine not visible	65	40	10	11	0	32
Total	100	100	100	100	100	100

7.2.2 Urbanization

The study sample was deliberately chosen from three different area types: built-up areas, rural areas with a main road and rural areas without a main road. The objective was to get a variety of background levels, but also to study annoyance with wind turbine sound in different landscapes. Of the respondents, 27% lived in built-up areas, 34% lived in rural areas with a main road and 39% lived in rural areas without a main road (table 7.5). Respondents in the lower groups of exposure to wind turbine sound more commonly lived in built-up areas than respondents in the groups of higher exposure.

Table 7.5: proportion of respondents per area type in relation to levels of wind turbine sound

n=725	Sound pressure levels, dBA					Total
	<30	30-35	35-40	40-45	>45	
Degree of urbanisation, %						
Built-up area	37	38	17	19	2	27
Rural with main road	27	32	36	38	46	34
Rural without main road	36	30	46	43	52	39
Total	100	100	100	100	100	100

7.2.3 Type of dwelling

Of the respondents, 77% lived on farms or in detached houses, while 22% lived in rented or owned apartments (table 7.6). Respondents in groups with low levels of wind turbine sound more commonly lived in apartments than those in groups with higher levels. This is in agreement with the higher proportion of respondents living in built-up areas in the lower exposure groups.

Table 7.6: type of dwelling in relation to levels of wind turbine sound

n=693	Sound pressure levels, dBA					Total
	<30	30-35	35-40	40-45	>45	
Type of dwelling, %						
Farm or detached house	65	68	86	92	98	77
Apartment	35	31	14	8	2	22
Total	100	100	100	100	100	100

7.2.4 Background sound levels

Immission levels of background sound for all respondents in the study were obtained from community noise maps as Lden (Lden scale with 5 dB intervals). In the selected areas, road traffic dominated the (calculated) background sound level. Therefore, the Lden values can be considered as an approximation of road traffic noise levels. Lden values of background sound were in the study negatively related to sound pressure levels of wind turbine sound ($r = -0.242$, $n = 725$, $p<0.001$). That means that respondents exposed to high levels of wind turbine sound were on average exposed to lower levels of road traffic sound than other respondents were (table 7.7).

Table 7.7: background sound levels (Lden) in relation to levels of wind turbine sound.

n=725	Sound pressure levels, dBA					Total
	<30	30-35	35-40	40-45	>45	
Lden, mean (SD)	49.0 (6.9)	46.6 (7.9)	44.8 (11.4)	43.9 (10.2)	41.1 (9.0)	46.0 (9.3)

7.2.5 Relationships between physical factors

Respondents living in built-up areas were less likely to see the wind turbines from their dwelling in comparison to respondents living in rural areas (table 7.8). They also more commonly lived in apartments.

Table 7.8: number of respondents who could not and who could see wind turbines from their dwelling and mean value of Sound levels for each sub-sample

	Area types			Type of dwelling	
	Built-up area	Rural with main road	Rural without main road	House or farm	Apartment
Visibility, %					
Not visible	89 (46%)	66 (27%)	75 (27%)	126 (24%)	92 (61%)
Visible	105 (54%)	177 (73%)	203 (73%)	407 (76%)	60 (39%)
Total	194 (100%)	243 (100%)	278 (100%)	533 (100%)	152 (100%)
Type of dwelling, %					
House or farm	126 (67%)	182 (78%)	230 (85%)		
Apartment	61 (33%)	52 (22%)	42 (15%)		
Total	187 (100%)	234 (100%)	272 (100%)		

As expected, respondents in built-up areas and rural areas with a main road were on average exposed to higher levels of road traffic sound than those living in rural areas with no main road (table 7.9). The differences were statistically significant (ANOVA, post hoc test LSD; built-up vs. rural with no main road, p<0.001; Rural with main road vs. rural without main road, p<0.001). Respondents in rural areas (with or without main road) were on average exposed to higher levels of wind turbine sound than those living in built-up areas. Hence the three area types represented different sound conditions; high Lden from road traffic and low SPL from wind turbines (built-up), high Lden and high SPL (rural with main road) and low Lden and high SPL (rural without main road).

Table 7.9: mean values of exposure levels in three types of area

N=725	Built-up areas n = 199	Rural areas with main road n = 245	Rural areas without main roads n = 281
	Mean (SD)	Mean (SD)	Mean (SD)
Lden	49.1 (6.3)	49.2 (8.4)	41.0 (9.5)
SPL from wind turbines	32.5 (4.7)	36.2 (6.6)	36.1 (6.7)

7.3 Individual factors

INDIVIDUAL FACTORS
Age and gender
Economical benefit from wind turbines
Education level and employment
Living conditions
Attitude and noise sensitivity

7.3.1 Age and gender

The mean age of the respondents was 51 years with a higher average age in the groups with low levels of sound and a lower average age at higher sound levels (table 7.10). The correlation between age and sound levels was statistically significant ($r = -0.21$, $n = 703$, $p<0.001$), *i.e.* age decreased with increasing sound levels. Of the respondents, 51% were men and 49% were women. The proportion of men and women differed somewhat between groups of sound levels. The uneven distributions of age and gender in relation to sound levels make it important to adjust for these two factors when relationships between sound levels and response are explored.

Table 7.10: age and gender in relation to levels of wind turbine sound

	Sound pressure levels, dBA					Total
	<30	30-35	35-40	40-45	>45	
Age (n=703)						
Mean (SD)	57 (15.0)	57 (15.4)	52 (14.9)	51 (14.7)	48 (10.7)	54 (15.0)
Gender (n=706), %						
Male	44	52	55	54	51	51
Female	56	48	45	46	49	49
Total	100	100	100	100	100	100

7.3.2 Economical benefits

Of the respondents, 14% ($n = 100$) benefited economically from wind turbines by owning wind turbines or shares of wind turbines, or otherwise. These respondents more commonly lived in rural areas; only 3 respondents benefited economically and lived in a built-up area. Respondents who benefited economically were exposed to higher levels of wind turbine noise than others (table 7.11). The difference was statistically significant ($t = -16.1$, $p<0.001$). In the group of respondents exposed to levels of wind turbine sound below 30 dBA, only 2% benefited economically, while among respondents in the group exposed to more than 45 dBA, 67% benefited.

Table 7.11: economical benefits in relation to levels of wind turbine sound

n=699	Sound pressure levels, dBA					Total
	<30	30-35	35-40	40-45	>45	
Economical benefits, %						
Benefited economically	2	3	10	34	67	14
Did not benefit economically	98	97	90	66	33	86
Total	100	100	100	100	100	100

7.3.3 Education and employment

Respondents were classified into three groups in accordance with their educational level; primary (lower general or vocational), secondary (secondary general or vocational) and higher (general or vocational, university). The proportion of respondents with higher education was larger in the group of respondents exposed to high levels of wind turbine sound (>45 dBA) than among other respondents (table 7.12). Respondents with higher education also more often benefited economically from the wind turbines.

People who spend a lot of time at home could be expected to be more annoyed by wind turbine sound. Of the respondents, 31% were employed, 19% were retired and 26% worked at home (table 7.12). However, 25% had classified their occupation as "other". Included in this category were mainly self-employed persons and farmers.

Table 7.12: education and employment in relation to levels of wind turbine sound

	Sound pressure levels, dBA					Total
	<30	30-35	35-40	40-45	>45	
Education (n=701), %						
Primary	25	27	21	14	6	23
Secondary	38	42	41	53	44	43
Higher	32	32	38	33	49	35
Total	100	100	100	100	100	100
Employment status (n=704), %						
Employed	41	27	34	24	19	31
Domestic work or working at home	22	22	24	34	41	26
Retired	22	28	15	10	0	19
Other	16	23	26	33	40	25
Total	100	100	100	100	100	100

7.3.4. Living conditions

The respondents had on average lived 18 years at their current dwelling (table 7.13). Most respondents were satisfied with their living conditions. Of the respondents, 23% reported changes for the better in the living environment during the last years. Changes for the worse in the living environment were reported by 36% of the respondents. The nature of these changes are described in section Appendix I: *Remarks in the questionnaires added by respondents.*

Table 7.13: characteristics of the respondents at each 5 dBA interval of sound levels

	Sound pressure levels, dBA					Total
	<30	30-35	35-40	40-45	>45	
Years at this address (n=715)						
Mean (SD)	18 (13)	17 (14)	17 (13)	22 (15)	16 (15)	18 (15)
Satisfaction with the living environment (n=717), %						
Satisfied or very satisfied	92	91	93	90	97	92
Not satisfied	8	9	7	10	3	8
Total	100	100	100	100	100	100
Changes for the better (n=710), %						
No	75	79	76	86	67	77
Yes	25	21	24	14	33	23
Total	100	100	100	100	100	100
Changes for the worse (n=707), %						
No	73	65	58	60	60	64
Yes	27	35	43	40	40	36
Total	100	100	100	100	100	100

7.3.5 Attitude and noise sensitivity

General attitude towards wind turbines was measured on a 5-point scale from very positive to very negative. Of the respondents, 14% were negative or very negative towards wind turbines in general (table 7.14), while 56% were positive or very positive. General attitude was not correlated with levels of wind turbine sound, *i.e.* respondents in groups with higher levels of wind turbine sound were not more negative or positive than those in groups with lower levels.

Of the respondents, 36% were negative or very negative to the impact of the wind turbines on the landscape scenery (table 7.14). On the other hand, 21% were positive or very positive. No difference was found between respondents who could see wind turbines from their dwelling and those who could not. Attitude towards the impact of wind turbines on the landscape was not correlated with levels of wind turbine sound.

Noise sensitivity is well-known from community noise studies to be associated with noise annoyance. Noise sensitivity is in those studies seen as a personal trait that is independent of sound exposure. In this study, WINDFARMperception, noise sensitivity was measured on a 4-point scale from "not at all sensitive" to "very sensitive". Of the respondents, 30% were rather or very sensitive to noise. The proportions of respondents that rated themselves as rather or very sensitive to noise were approximately the same in all five groups of sound levels, and hence there was no statistically significant correlation between noise sensitivity and levels of wind turbine sound.

Table 7.14: attitude and noise sensitivity in relation to levels of wind turbine sound

	Sound pressure levels, dBA					Total
	<30	30-35	35-40	40-45	>45	
Attitude to wind turbines in general (n=708), %						
Rather or very negative	10	14	19	17	9	14
Not negative	90	86	81	83	91	86
Total	100	100	100	100	100	100
Attitude to the impact of wind turbines on the landscape (n=704), %						
Rather or very negative	33	36	45	39	20	36
Not negative	67	64	55	61	80	64
Total	100	100	100	100	100	100
Noise sensitivity (n=713), %						
Rather or very sensitive	36	25	31	31	23	30
Not sensitive or slightly sensitive	64	75	69	69	77	70
Total	100	100	100	100	100	100

The respondents were asked to judge several aspects of wind turbines on 5-point scales with the third point supposed to be a neutral judgment. The wind turbines were perceived as relatively ugly, repulsive, unnatural and annoying, but also as relatively efficient, environmental friendly, necessary and harmless according to the mean values of ratings of eight pairs of judgment terms (table 7.15).

Table 7.15: judgments of wind turbines

	n	Mean	SD	Skewness	Kurtosis
Efficient – inefficient	629	2.5	1.26	0.45	-0.71
Environmental friendly – not environmental friendly	652	2.1	1.27	0.97	-0.14
Pretty – ugly	643	3.5	1.30	-0.49	-0.84
Necessary – unnecessary	647	2.4	1.28	0.57	-0.65
Inviting – repulsive	625	3.4	1.19	-0.27	-0.63
Natural – unnatural	636	3.4	1.37	-0.41	-1.03
Annoying – blends in	633	2.7	1.15	0.12	-0.63
Dangerous -harmless	631	3.5	1.28	-0.50	-0.69

From the terms of judgments, two factors describing different aspects of wind turbines were constructed with factor analysis. This was done to capture different aspects of judgments towards wind turbines. Factor 1 comprised items that could be connected to the looks of the wind turbines and the factor was therefore named "Visual judgments" (table 7.16). Factor 2 comprised items describing electricity generation and its contribution to less environmental harm. This factor was named "Utility judgments". The two constructed factors reflected 75%

of the variance of the items. Two items did not fit into the factor analysis; annoying – blends in and dangerous - harmless.

Table 7.16: factor loadings of two factors derived from 6 of the pair of judgment terms

n=595	Visual judgment (Factor 1) alpha = 0.850	Utility judgment (Factor 2) alpha = 0.804
Pretty – ugly	0.884	0.127
Inviting – repulsive	0.880	0.201
Natural – unnatural	0.829	0.152
Environmental friendly – not environmental friendly	0.039	0.841
Efficient – inefficient	0.213	0.836
Necessary – unnecessary	0.235	0.810

7.3.6 Relationships between individual factors

Respondents who benefited economically from wind turbines were on average younger than those who did not and hence on average more healthy, though not less psychologically distressed or stressed (see section 7.8 below). They had higher education and more commonly worked at home than others. Respondents who benefited economically were less negative to wind turbines in general and to the impact of wind turbines on the landscape scenery, but rated themselves as noise sensitive to the same degree as those who did not benefit.

Respondents with higher education rated their sensitivity for noise higher than the others. They were younger and had less chronic diseases, but did not differ in psychological distress or stress score (see section 7.8 below) from those with lower education. They were not more negative to wind turbines in general, but were more negative to the impact of the turbines on the landscape scenery.

Variables measuring different aspects of attitude and noise sensitivity were correlated to each other. Attitude towards the impact of wind turbines on the landscape scenery was correlated with general attitude, to the factor "visual judgment" as expected, and to a lesser degree with the factor "utility judgment" (table 7.17). Noise sensitivity was correlated with all the attitude variables. As expected, the two constructed factors of judgments were not correlated.

Table 7.17: correlations between variables measuring attitude and noise sensitivity.

Spearman's rank-order correlation	1	2	3	4	5
1. Noise sensitivity	-				
2. Attitude to impact on landscape	0.259***	-			
3. General attitude	0.140***	0.646***	-		
4. Factor Visual judgments	0.212***	0.602***	0.501***	-	
5. Factor Utility judgments	0.105*	0.381***	0.513***	0.053	-

***p<0.001, *p<0.05

7.4 Response to wind turbines

RESPONSE
Perception
Annoyance
Occurrence
Sound character

7.4.1 Response to exposures from wind turbines

In this study response was measured to several types of exposure from wind turbines in the living environment. Of the respondents, 17% were rather or very annoyed by the sound from rotor blades, 13% by the changes in view and 9% by the movement of the rotor blades (table 7.18). Also, 6% of the respondents were rather or very annoyed by blinking shadows indoors and/or moving shadows outdoors.

Table 7.18: response to different types of exposures from wind turbines; number of respondents and proportions of respondents

	Do not notice	Notice but not annoyed	Slightly annoyed	Rather annoyed	Very annoyed	Total
Blinking shadows indoors	464 (69%)	91 (14%)	75 (11%)	20 (3%)	19 (3%)	669 (100%)
Moving shadows outdoors	434 (65%)	130 (20%)	63 (9%)	15 (2%)	23 (4%)	665 (100%)
Sound of rotor blades	430 (65%)	57 (9%)	60 (9%)	45 (7%)	69 (10%)	661 (100%)
Movement of rotor blades	344 (52%)	196 (29%)	70 (10%)	30 (5%)	27 (4%)	667 (100%)
Changed view	283 (43%)	201 (30%)	91 (14%)	48 (7%)	42 (6%)	665 (100%)
Vibrations	574 (90%)	39 (6%)	18 (3%)	4 (1%)	3 (0%)	638 (100%)

The respondents were asked how often they were affected by different exposures from wind turbines. Most often the respondents were affected by the changed view: 20% reported that they were affected by changed view once a week or more often (table 7.19). With the same frequency, 17% were affected by sound from rotor blades and 15% by movement of the rotor blades.

Table 7.19: frequency of perceived annoyance with different exposures from wind turbines

	Almost never	At least once in the past year	At least once a month	At least once a week	Almost daily	Total
Blinking shadows indoors	529 (80%)	44 (7%)	38 (6%)	30 (5%)	22 (3%)	663 (100%)
Moving shadows outdoors	520 (79%)	43 (7%)	37 (6%)	27 (4%)	32 (5%)	659 (100%)
Sound of rotor blades	430 (65%)	57 (9%)	60 (9%)	45 (7%)	69 (10%)	661 (100%)
Movement of rotor blades	498(76%)	31 (5%)	27 (4%)	26 (4%)	73 (11%)	655 (100%)
Changed view	442 (68%)	46 (7%)	29 (4%)	22 (3%)	113 (17%)	652 (100%)
Vibrations	615 (96%)	9 (1%)	7 (1%)	7 (1%)	6 (1%)	644 (100%)

7.4.2 Response to wind turbine sound

Annoyance with sound from wind turbines was investigated further. Five variables measuring annoyance with wind turbine sound, outdoors or indoors, were included in the study. The variables were all highly correlated (all p-values <0.001). The five questions also showed high internal consistency (alpha = 0.87). This means that the measurements were reliable. One of these measurements (question 10, see Appendix A) will be used as the main outcome in this report. The results presented here would have been similar if another of the five measurements had been chosen as the main outcome.

Early in the questionnaire, in question 10, response to wind turbine sound was assessed with a 5-point scale from "do not notice" to "very annoyed" among other disturbances. Of the respondents, 60% reported that they noticed sound from wind turbines outdoors and 33% reported noticing the sound indoors. Furthermore, 10% of the respondents were rather or very annoyed by wind turbine sound outdoors and 6% were rather or very annoyed by wind turbine sound indoors (table 7.20).

Table 7.20: response to wind turbine sound, outdoors and indoors, measured on a 5-point scale

	Do not notice	Notice but not annoyed	Slightly annoyed	Rather annoyed	Very annoyed	Total
Sound outdoors	284 (40%)	259 (37%)	92 (13%)	44 (6%)	29 (4%)	708 (100%)
Sound indoors	465 (67%)	139 (20%)	54 (8%)	21 (3%)	20 (3%)	699 (100%)

Respondents who could hear wind turbine sound at their dwelling were asked if the sound was more distinctive in some situations. Most often, the sound of the wind turbines was perceived as louder when the wind was blowing from the wind turbines towards the dwelling and when the wind was strong (table 7.21). Also, 40% of the respondents that could hear the wind turbine sound reported that the sound was louder at night time and 32% reported it was louder on warm summer evenings.

Table 7.21: perception of loudness in different situations. Only respondents who could hear wind turbine sound at their dwelling

	Less loud	Louder	No difference	Do not know	Total
Wind from turbine towards dwelling	18 (5%)	230 (69%)	44 (13%)	43 (13%)	335 (100%)
Wind from dwelling towards turbine	176 (56%)	37 (12%)	45 (14%)	58 (18%)	316 (100%)
Weak or no wind	215 (69%)	46 (15%)	28 (9%)	24 (8%)	313 (100%)
Strong wind	59 (18%)	220 (67%)	32 (10%)	17 (5%)	328 (100%)
Warm summer evenings	85 (27%)	102 (32%)	82 (26%)	52 (16%)	321 (100%)
Nighttime	70 (22%)	125 (40%)	80 (25%)	41 (13%)	316 (100%)
Sideways	75 (26%)	16 (6%)	97 (33%)	105 (36%)	293 (100%)

The most common description of the wind turbine sound was "swishing/lashing": 75% of the respondents who could hear the sound thought that this was a suitable term to characterize the sound (table 7.22). "Rustling" was the second most common description, followed by "a low frequency/low pitch sound". A “pure tone” was reported by only 3% of those that could hear the sound.

Table 7.22: characteristics of the wind turbine sound. Only respondents who could hear wind turbine sound at their dwelling

How would you describe the sound of wind turbines?	N*	yes
A pure tone	335	11 (3%)
Thumping/throbbing	335	24 (7%)
Swishing/lashing	335	251 (75%)
Whistling/screeching	335	32 (10%)
Rustling	335	83 (25%)
Scratching/squeaking	335	10 (3%)
A low frequency/low pitch sound	335	46 (14%)
Resounding	335	23 (7%)
Other	335	23 (7%)

*Number of respondents who answered that they could hear sound from wind turbines

Respondents that characterized the sound from wind turbines as “swishing/lashing”, the most common classification, were more likely to also be annoyed by the sound than others (Z_{MWU} = -3.2; p<0.001). Respondents annoyed (rather or very) by wind turbine sound more often characterized the sound as “thumping/throbbing”, “swishing/lashing”, whistling/screeching”, “scratching/squeaking” and “resounding” than respondents who were not annoyed by the sound (table 7.23).

Table 7.23: characteristics of the wind turbine sound among respondents who were not annoyed by wind turbine sound and among respondents who were annoyed; only respondents who could hear wind turbine sound at their dwelling

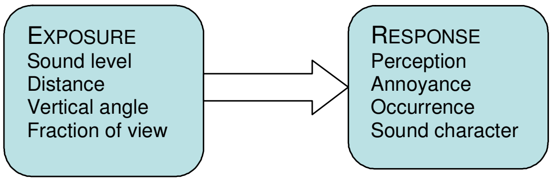
How would you describe the sound of wind turbines?	Not annoyed by wind turbine sound	Annoyed by wind turbine sound	p-values
A pure tone	4%	0%	0.127
Thumping/throbbing	**4%**	**17%**	**<0.001**
Swishing/lashing	**69%**	**82%**	**<0.05**
Whistling/screeching	**6%**	**18%**	**<0.01**
Rustling	22%	23%	0.871
Scratching/squeaking	**2%**	**9%**	**<0.05**
A low frequency/low pitch sound	12%	20%	0.077
Resounding	**3%**	**21%**	**<0.001**
Other	6%	9%	0.589

Respondents who benefited economically from wind turbines were less annoyed by wind turbine sound than other respondents, despite higher exposure levels. Of those who did not benefit, 12% were rather or very annoyed, compared to 3% of those who did benefit (table 7.24). This difference in distribution was statistically significant (Z_{MWU} = -2.55, p<0.05).

Table 7.24: response to wind turbine sound outdoors among respondents who did or did not benefit economically from wind turbines

	Do not notice	Notice but not annoyed	Slightly annoyed	Rather annoyed	Very annoyed	Total
Sound outdoors (No economical benefits)	255 (44%)	184 (31%)	78 (13%)	41 (7%)	28 (5%)	586 (100%)
Sound outdoors (Economical benefits)	15 (15%)	68 (69%)	13 (13%)	2 (2%)	1 (1%)	99 (100%)

7.5 Response to wind turbines related to exposure



Response to wind turbine sound outdoors (5-point scale from "do not notice" to "very annoyed") was correlated with levels of wind turbine sound ($r_s = 0.501$, $n = 708$, $p<0.001$); the probability of noticing and/or being annoyed by wind turbine sound increased with increasing sound levels. The distribution of respondents annoyed by wind turbine sound is shown in table 7.25.

Table 7.25: response to wind turbine sound outdoors in relation to 5 dBA-intervals of sound levels (all respondents)

Response outdoors	Sound pressure levels, dBA					
	<30	30-35	35-40	40-45	>45	Total
Do not notice	134 (75%)	99 (47%)	34 (21%)	12 (13%)	5 (8%)	284 (40%)
Notice, but not annoyed	36 (20%)	77 (36%)	65 (41%)	43 (46%)	38 (59%)	259 (37%)
Slightly annoyed	4 (2%)	21 (10%)	32 (20%)	21 (23%)	14 (22%)	92 (13%)
Rather annoyed	2 (1%)	13 (6%)	19 (12%)	6 (7%)	4 (6%)	44 (6%)
Very annoyed	2 (1%)	3 (1%)	9 (6%)	11 (12%)	4 (6%)	29 (4%)
Total	178 (100%)	213 (100%)	159 (100%)	93 (100%)	65 (100%)	708 (100%)

The same result is illustrated in figure 7.1 as added proportions of respondents who noticed or/and were annoyed by wind turbine sound. The proportion of respondents who noticed the sound increased with increasing sound levels. Of the respondents, 80% or more noticed sound from wind turbines when the sound levels were 40 dBA or higher. The proportion of respondents who were annoyed by wind turbine sound increased with increasing sound levels up to 45 dBA, and after that decreased. Among respondents in the group 40-45 dBA, 19% were rather or very annoyed, and 12% were very annoyed. The confidence intervals do not overlap in most of the increasing part of the curves which means that the increase is statistically significant. However, at sound pressure levels of 40 dBA and higher, the confidence intervals of the different 5 dBA-intervals of sound levels overlap.

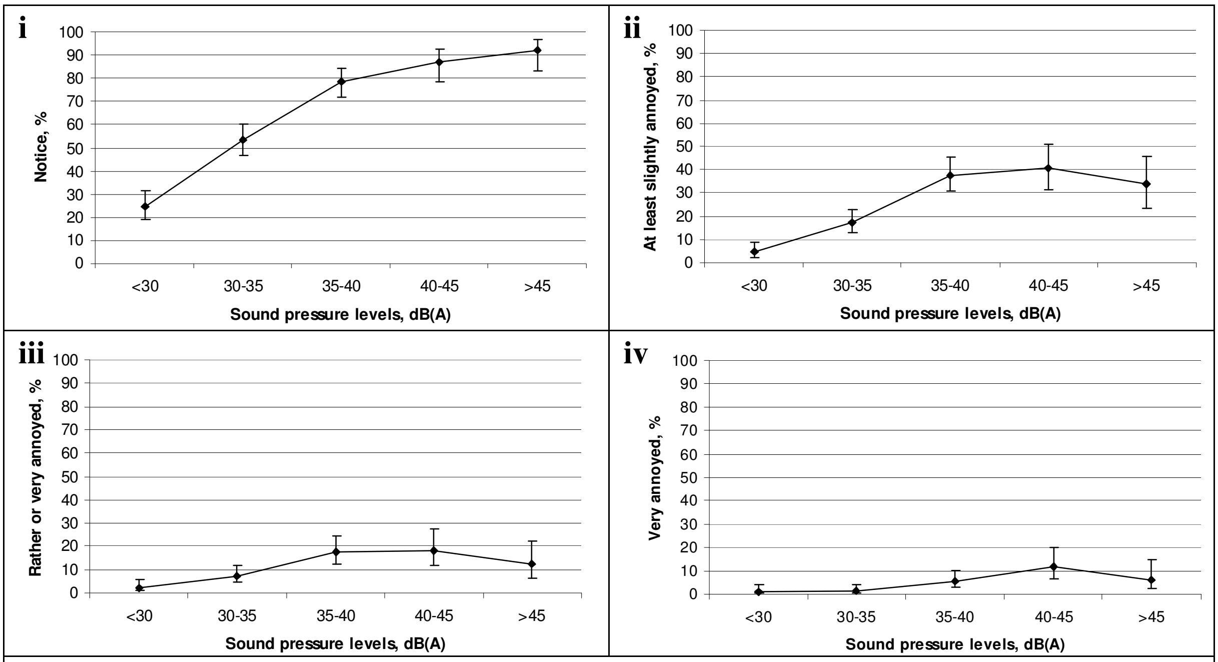


Figure 7.1: relationships between levels of wind turbine sound in dBA and response to wind turbine sound (all respondents; n = 708) measured on a 5-point scale: (i) point 2-5 ("notice but not annoyed" through "very annoyed"; i.e. respondents who noticed sound), (ii) point 3-5 ("slightly annoyed" through "very annoyed"), (iii) point 4-5 ("rather annoyed" and "very annoyed"), and (iv) point 5 (very annoyed). With 95% confidence intervals.

The large differences in proportion annoyed among respondents that did not benefit economically from the wind turbines and respondent who did, and the fact that most of the respondents that benefited lived close to the wind turbines, made it interesting to also study relationships between sound levels and response only among respondents who did not benefit. Table 7.26 shows the number and proportion of respondents that were annoyed by sound from wind turbines and who did not benefit economically from the turbines.

Table 7.26: response to wind turbine sound outdoors in relation to 5 dBA-intervals of sound levels; only respondents who did not benefit economically from wind turbines

Response outdoors	Sound pressure levels, dBA					
	<30	30-35	35-40	40-45	>45	Total
Do not notice	124 (75%)	92 (46%)	30 (21%)	7 (12%)	2 (10%)	255 (44%)
Notice, but not annoyed	34 (21%)	71 (36%)	52 (37%)	22 (37%)	5 (24%)	184 (31%)
Slightly annoyed	4 (2%)	20 (10%)	30 (21%)	16 (27%)	8 (38%)	78 (13%)
Rather annoyed	2 (1%)	13 (7%)	19 (14%)	4 (7%)	3 (14%)	41 (7%)
Very annoyed	2 (1%)	3 (2%)	9 (6%)	11 (18%)	3 (14%)	28 (5%)
Total	166 (100%)	199 (100%)	140 (100%)	60 (100%)	21 (100%)	586 (100%)

The relationships between sound levels and response among respondents who did not benefit economically from wind turbines are also shown in figure 7.2. The confidence intervals are rather large at the higher levels of exposure due to a small number of respondents at these intervals. There was no significant difference in perception of the sound between respondents who benefited economically from wind turbines and those who did not; the likeliness to notice the sound was about 80% or more above 40 dBA. However, the proportion of respondents annoyed by wind turbine sound is higher when respondents that benefited economically are excluded. Of the respondents in the group 40-45 dBA, 25% were rather or very annoyed by the sound and 18% were very annoyed.

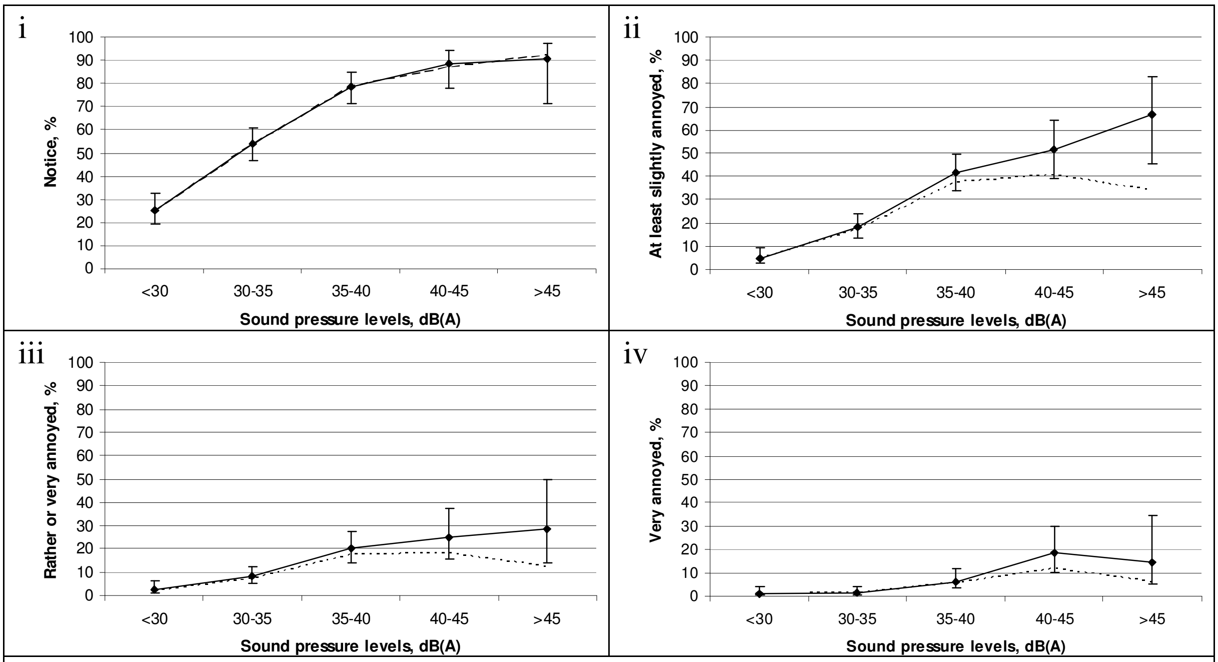


Figure 7.2: same as figure 7.1, but for respondents who did not benefit economically (n = 586); dotted lines indicate the response among all respondents (n = 708); (for 22 respondents economical benefit unknown)

The relationship between sound levels and response to wind turbine sound were tested with binary logistic regression. The measured response to wind turbine sound was dichotomized into "do not notice" (point 1) versus "notice" (points 2 through 5) and assigned to the dependent variable. Sound level (continuous scale in dBA), age (continuous scale in years), gender (male/female) and economical benefits (no/yes) were assessed as independent variables and entered into the regression simultaneous. For a description of how the odds ratios (OR) should be interpreted, see section 6.2.3 *Statistical analyses*. The odds for noticing sound from wind turbines increased statistically significant with increasing sound levels (table 7.27).

Table 7.27: relationship between sound levels and perception of wind turbine sound, adjusted for age, gender and economical benefits

Do not notice vs. notice wind turbine sound H-L test p = 0.144	OR	95% CI
Sound levels*	**1.25**	**1.197 – 1.301**

*Adjusted for age, gender and economical benefits.

The measured response to wind turbine sound was dichotomized into “not annoyed” (point 1 through 3) versus “annoyed” (point 4 through 5). The odds for being annoyed by wind turbine sound also increased with increasing sound levels (table 7.28).

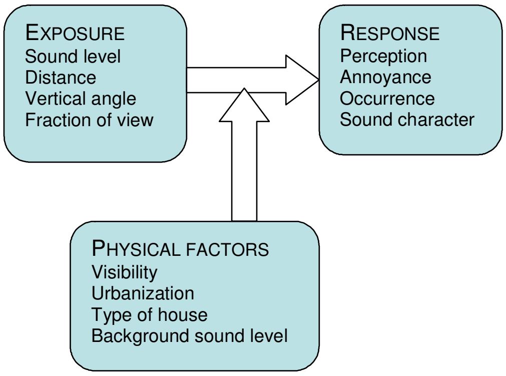
Table 7.28: relationship between sound levels and annoyance with wind turbine sound, adjusted for age, gender and economical benefits

Not annoyed vs. annoyed H-L test** p = 0.434	OR	95% CI
Sound levels*	**1.18**	**1.121 – 1.235**

*Adjusted for age, gender and economical benefits.

For the standardized measurements of response, see Appendix F.

7.6 Influence of physical factors on response to wind turbine sound



Several physical factors were hypothesized to increase the odds for noticing sound from wind turbines. They were first tested one by one in a binary logistic regression with the outcome "do not notice" vs. "notice" wind turbine sound. Sound levels, age, gender and economical benefits were adjusted for in the test. Thus, if a statistically significant increase in odds was found for a tested variable, this variable supposedly had an impact on the likeliness to hear wind turbine sound despite sound levels, age, gender or economical benefits.

Respondents who could see at least one wind turbine from their dwelling were more likely to notice the sound from wind turbines than other respondents (table 7.29). The degree of urbanisation did not have a statistically significant impact on the possibility to notice sound from wind turbines. When the two types of rural areas were compared with the built-up areas, no differences in odds were found. Though there was a difference between both rural area types in noticing the sound (less when there was a main road, more when there was no such road), this difference was not statistically significant. Respondents living in apartments were less likely to notice the sound in comparison with those living in other types of dwellings. Background (road traffic) sound levels had a negative, though very small effect; the possibility to notice wind turbine sound decreased with increasing background levels as expected.

Table 7.29: relationship between physical factors and noticing sound from wind turbines, adjusted for sound levels, age, gender and economical benefits; variables were tested one by one

Do not notice vs. notice wind turbine sound	OR	95% CI
Visibility, H-L test p = 0.922		
Visibility (no/yes)*	**4.16**	**2.717 – 6.372**
Urbanization, H-L test p = 0.333		
Built-up area*	1.00	
Rural area with a main road*	0.66	0.416 – 1.052
Rural area without main road*	1.23	0.785 – 1.940
Type of dwelling, H-L test p = 0.465		
Type of dwelling (house/apartment)*	**0.56**	**0.365 – 0.869**
Background sound, H-L test p = 0.124		
Lden*	**0.98**	**0.958 – 0.999**

*Adjusted for sound levels, age, gender and economical benefits.

The factors found to be related with noticing sound from wind turbines were tested simultaneously. Seeing at least one wind turbine from the dwelling still increased the odds for noticing the sound and increased background sound levels decrease the odds, though very slightly (table 7.30). However, type of housing no longer influenced the possibility of noticing the sound. This could be due to the correlation between type of dwelling and visibility as described above; respondents living in houses or farms more commonly could see wind turbines from their dwelling than respondents living in apartments.

Table 7.30. Relationship between physical factors and noticing sound from wind turbines, adjusted for sound levels, age, gender and economical benefits; variables were tested simultaneously

Do not notice vs. notice wind turbine sound H-L test p = 0.860	OR	95% CI
Visibility (no/yes)*	**3.97**	**2.540 – 6.205**
Type of dwelling (house/apartment)*	0.74	0.468 – 1.183
Lden*	**0.98**	**0.955 – 0.998**

*Adjusted for s levels, age, gender and economical benefits.

The influences of physical factors on the probability of being annoyed by wind turbine sound were also explored. Visibility was strongly related to annoyance; respondents who could see at least one wind turbine from their dwelling were more likely to be annoyed by the sound than respondents who could not see any wind turbine (table 7.31). Respondents living in a rural area with a main road were less likely to be annoyed by wind turbine sound than respondents living in a built-up area, even though sound levels of wind turbine sound were just as high. Living in an apartment lowered the odds for being annoyed by the sound from wind turbines. Levels of background (road traffic) sound had no relationship with annoyance due to wind turbine sound; increased levels of background sound did not decrease the odds for annoyance.

Table 7.31: relationship between physical factors and being annoyed by sound from wind turbines, adjusted for sound levels, age, gender and economical benefits; variables were tested one by one

Not annoyed vs. annoyed	OR	95% CI
Visibility, H-L test p = 0.590		
Visibility (no/yes)*	**12.51**	**2.937 – 53.271**
Urbanization, H-L test p = 0.650		
Built-up area*	1.0	
Rural area with a main road*	**0.24**	**0.107 – 0.522**
Rural area without main road*	0.67	0.356 – 1.252
Type of dwelling, H-L test p = 0.882		
Type of dwelling (house/apartment)*	**0.40**	**0.162 – 0.980**
Background sound, H-L test p = 0.960		
Lden*	1.01	0.986 – 1.042

*Adjusted for sound levels, age, gender and economical benefits.

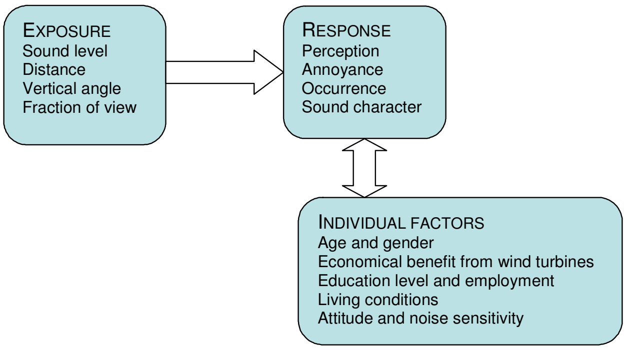
The influence of visibility on annoyance with wind turbine sound was large, also when the variables were tested simultaneously (table 7.32). Living in an area with a main road in comparison with a built-up area still decreased the odds for being annoyed. However, type of dwelling was no longer associated with annoyance due to wind turbine sound.

Table 7.32: relationship between physical factors and being annoyed by sound from wind turbines, adjusted for sound levels, age, gender and economical benefits; variables were tested simultaneously

Not annoyed vs. annoyed H-L test p = 0.690	OR	95% CI
Visibility (no/yes)*	**12.0**	**2.782 – 51.910**
Urbanization		
Built-up area*	1.0	
Rural area with a main road*	**0.20**	**0.084 – 0.448**
Rural area without main road*	0.55	0.282 – 1.077
Type of dwelling (house/apartment)*	0.12	0.189 – 1.210

*Adjusted for sound levels, age, gender and economical benefits.

7.7 Influence of individual factors on annoyance with wind turbine sound



The relationships between individual factors and annoyance with wind turbine sound were also tested. Some of the factors, such as age and gender, could be considered as factors that actually could influence the odds for being annoyed by the sound (even though it cannot be excluded that there is another related factor that actually causes the effect). Other factors, such as attitude, are more ambiguous; we do not know if the attitude has an influence on annoyance or if annoyance leads to a negative attitude. The statistical tests can only show whether there is a relationship between attitude and annoyance, not which one is the cause and which one the effect.

Age was found to be related to annoyance with wind turbine sound (table 7.33). Older respondents were more likely to be annoyed than younger ones. No difference was found between men and women. Benefiting economically from wind turbines decreased the odds for being annoyed by the sound as shown before.

Table 7.33: relationship between individual factors and annoyance with sound from wind turbines, adjusted for sound levels; variables were tested one by one

Not annoyed vs. annoyed	OR	95% CI
Age, H-L test p = 0.224		
Age (year)*	**1.03**	**1.010 – 1.049**
Gender, H-L test p = 0.017		
Gender (male, female)*	0.93	0.558 – 1.531
Economical benefits, H-L test p = 0.152		
Economical benefits (no/yes)*	**0.05**	**0.014 – 0.186**

*Adjusted for sound levels.

Respondents who were highly educated were more likely to be annoyed by the sound than respondents with primary education (table 7.34). No differences between respondents that were employed, and supposedly not so much at home, and other, non-employed respondents were found. Respondents that were not satisfied with the living environment were more likely to be annoyed by wind turbine sound than others. Positive changes in the living environment were not associated with annoyance, while negative changes were. All measurements of attitude as well as noise sensitivity were positively related to annoyance with wind turbine sound: respondents who were negative towards the wind turbines were more likely to be annoyed or vice versa.

Table 7.34: relationship between individual factors and being annoyed by sound from wind turbines, adjusted for sound levels, age, gender and economical benefits; variables were tested one by one

Not annoyed vs. annoyed	OR	95% CI
Education, H-L test p = 0.454		
Primary*	1.0	
Secondary*	1.56	0.708 – 3.421
Higher*	**2.29**	**1.020 – 5.122**
Employment, H-L test p = 0.315		
Employed	1.00	
Home workers*	1.19	0.532 – 2.647
Retired*	1.66	0.648 – 4.256
Others*	1.04	0.477 – 2.260
Living conditions, H-L test p=0.439		
Dissatisfaction with living environment (5-point scale)*	**1.92**	**1.377 – 2.675**
Positive changes in the living environment, H-L test p=607		
Changes for the better (no/yes)*	0.59	0.288 – 1.190
Negative changes in the living environment, H-L test p=0.835		
Changes for the worse (no/yes)*	**6.35**	**3.448 – 11.681**
General attitude, H-L test p = 0.915		
Attitude to wind turbines in general (5-point scale)*	**3.18**	**2.371 – 4.261**
Impact on landscape, H-L test p = 0.491		
Attitude to wind turbines' impact on the landscape (5-point scale)*	**4.10**	**2.841 – 5.908**
Noise sensitivity, H-L test p = 0.181		
Noise sensitivity (4-point scale)*	**1.94**	**1.513 – 2.489**
Visual judgment, H-L test p = 0.592		
Visual judgment (scale)*	**2.55**	**1.736 – 3.730**
Utility judgment, H-L test p = 0.320		
Utility judgment (scale)	**1.88**	**1.434 – 2.467**

*Adjusted for sound levels, age, gender and economical benefits.

The degree of education was no longer statistically significant when the variables were tested simultaneously (table 7.35). Changes for the worse, attitude to wind turbines in general and attitude to wind turbines' impact on the landscape were still related to annoyance with wind turbine sound. Visual judgment and utility judgment were not tested as they were strongly correlated with the two other variables of attitude.

Table 7.35: relationship between individual factors and being annoyed by sound from wind turbines, adjusted for sound levels, age, gender and economical benefits; variables were tested simultaneously

Not annoyed vs. annoyed, H-L test p = 0.663	OR	95% CI
Education		
Primary*	1.0	
Secondary*	0.87	0.330 – 2.317
Higher*	1.30	0.484 – 3.512
Satisfaction with living environment (5-point scale)*	1.20	0.782 – 1.845
Changes for the worse (no/yes)*	**2.82**	**1.340 – 5.927**
Attitude to wind turbines in general (5-point scale)*	**1.79**	**1.217 – 2.623**
Attitude to wind turbines' impact on the landscape (5-point scale)*	**2.11**	**1.291 – 3.451**
Noise sensitivity (4-point scale)*	1.30	0.956 – 1.777

*Adjusted for sound levels, age, gender and economical benefits.

7.8 Effects

EFFECTS
Health
Psychological distress
Stress
Sleep quality

One of the objectives of the study was to explore the impact of wind turbines on health and well-being among people living in the vicinity of wind farms. Health and well-being among the respondents were measured by several questions in the questionnaire: respondents were asked if they had any chronic disease (no/yes) and if so, if they suffered from diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, migraine or other diseases. Of the respondents, 25% reported to have a chronic disease (table 7.36). Most common among chronic diseases or health symptoms was high blood pressure. The proportion of respondents who suffered from chronic diseases or health symptoms increased statistically significant with increasing age, except for tinnitus and migraine (t-tests, $p<0.001$). No statistically significant differences between men and women were found, except for migraine, which was more common among female respondents.

Psychological distress was measured with the General Health Questionnaire (GHQ), ranging from 0 to 12, with a higher value corresponding to a higher degree of psychological distress. The GHQ-score was negatively correlated with age ($r = -0.108$, $n = 703$, $p<0.01$), which means that younger respondents were more psychological distressed. No statistically significant difference in GHQ-score was found between male and female respondents.

A stress scorewas constructed from 13 items measuring stress in the questionnaire with a 4-point scale rated from "(almost) never" to "(almost) daily" with factor analysis so that the mean value was 0 and the standard deviation 1. The factor analysis showed that 6 of the items could form a factor that described symptoms of stress (alpha: 0.840; minimum: -2.2; maximum: 4.4). The items were: feeling tense or stressed, feeling irritable, having mood changes, being depressed, suffering from undue tiredness and having concentration problems. The stress score was negatively correlated with age ($r = -0.09$, $n = 639$, $p<0.05$), i.e. younger respondents had on average higher stress scores. No difference was found between male and female respondents

Sleep was measured with several variables. The question "How often have you had difficulties falling asleep in your home?" was answered on a 5-point scale from "(almost) never" to "(almost) daily". The question "How often is your sleep interrupted by sound?" was answered on the same 5-point scale. Of the respondents, 30% reported difficulties to fall asleep at least once a month and 25% reported interrupted sleep at least once a month (table 7.36). Difficulty with falling asleep was positively correlated with age ($r_s = 0.08$, $n = 691$, $p<0.05$). Older respondents more commonly had difficulties falling asleep. Interrupted sleep was negatively correlated with age ($r_s = -0.08$, $n = 699$, $p<0.05$); younger respondents were more often interrupted in their sleep. Differences between men and women were found for falling asleep. Women had more difficulties falling asleep than men ($Z_{MWU} = -3.18$, $p<0.01$). No differences between men and women were found for sleep interruption.

Table 7.36: health and sleep in relation to levels of wind turbine sound

	Sound pressure levels, dBA					Total
	<30	30-35	35-40	40-45	>45	
Chronic disease (n=717), %	32	25	25	18	15	25
Diabetes (n=725), %	4	4	4	2	3	4
High blood pressure (n=725), %	9	13	9	6	2	9
Tinnitus (n=725), %	4	3	1	1	2	2
Hearing impairment (n=725), %	4	6	3	3	2	4
Cardiovascular disease (n=725), %	6	7	8	1	0	6
Migraine (n=725), %	4	2	2	1	0	2
Psychological distress						
GHQ12-score (n=656), mean (SD)	3.2 (2.78)	3.1 (2.66)	3.8 (2.91)	3.8 (2.81)	3.6 (2.76)	3.4 (2.79)
Stress						
Stress score(n=656), mean (SD)	0.1 (1.04)	-0.1 (0.93)	0.1 (1.09)	0.0 (0.91)	-0.1 (1.02)	0.0 (1.00)
Sleep quality						
Difficulties falling asleep* (n=710), %	36	31	28	32	16	30
Interrupted in the sleep* (n=718), %	21	26	26	26	28	25

*At least once a month

Respondents who did not benefit economically from wind turbines reported more chronic diseases and health symptoms than those who benefited. They more often suffered from chronic disease in general, as well as from diabetes, high blood pressure and cardiovascular disease, and also more often had difficulties to fall asleep. The observed difference between the sub-samples regarding chronic diseases and health symptoms could be due to age effects; respondents who did not benefit economically were older than those who benefited, as shown above. Regarding variables measuring psychological distress and stress, respondents who did not benefit economically from wind turbines did not differ to any extent from those who did benefit economically.

Several of the variables measuring health and well-being were associated with each other. All variables measured on a continuous or ordinal scale were correlated (table 7.37). A respondent with a high GHQ-score more likely also had a high stress score.

Table 7.37. Relationship between measurements of health and well-being (Spearman's rank-order correlation; all p-values <0.001)

	GHQ-score	Stress score	Difficulties falling asleep	Interrupted in the sleep
GHQ-score	1			
Stress score	0.565 (n=652)	1		
Difficulties falling asleep	0.299 (n=707)	0.315 (n=651)	1	
Interrupted in the sleep	0.229 (n=715)	0.211 (n=211)	0.264 (n=710)	1

Respondents who reported that they had a chronic disease (n = 179) on average scored higher on the GHQ-score and the stress score than others (table 7.38). They also had more difficulties falling asleep.

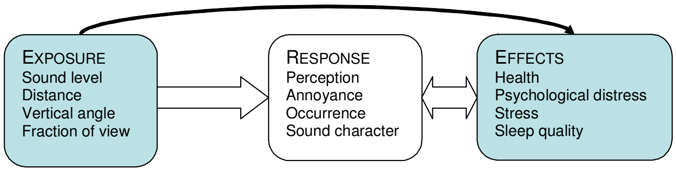
Table 7.38: relationships between chronic disease and other measurements of health, well-being and sleep

	Chronic disease	
GHQ-score	t = -2.02*	p<0.05
Stress score	t =-4.19*	p<0.001
Difficulties falling asleep	Z_{MWU}=-3.23**	p<0.01
Interrupted in the sleep	Z_{MWU}=-0.16**	p=0.873

*t-test **Mann-Whitney U-test

When the suggested diseases were analyzed separately, no associations between diabetes, high blood pressure, tinnitus, hearing impairment or cardiovascular disease on the one hand and the GHQ-score or the stress score on the other hand were found. Diabetes, tinnitus and hearing impairment were associated with difficulties to fall asleep. Migraine was related to the GHQ-score, the stress score, and both of the sleep variables; respondents suffering from migraine (n = 15) scored higher on all these measurements than respondents who did not suffer from migraine.

7.9 Relationships between exposure to wind turbine sound and effects



Possible adverse effects on health and well-being due to wind turbines have in previous studies been associated with noise annoyance, but not directly with the exposure. It could however not be excluded that there is a direct pathway between exposure and effects. It was in this study therefore of interest to explore relations between levels of wind turbine sound on the one hand and possible adverse effects on health and well-being on the other. This was done with binary logistic regression, with the variables measuring health or well-being as dependent variable.

The relationships between exposure and chronic diseases were analyzed together with age, gender and economical benefits in accordance with the findings reviewed above. Diseases and symptoms were chosen as dependent variables (reported disease/not reported disease). The independent variables sound levels (continuous scale), economical benefits (no/yes), age (continuous scale) and gender (male/female) were entered simultaneously into the regression. The results are shown in table 7.39. Values for adjusting variables are also shown. Sound levels were not related to any of the diseases or symptoms. Economical benefits were not associated with impaired health when adjusted for age and gender. Age was associated with chronic disease in general, diabetes, high blood pressure, hearing impairment and cardiovascular disease. Gender was associated with migraine.

Table 7.39: relationship between exposure of wind turbine sound and chronic diseases and health symptoms

	OR	95% CI
Chronic disease, (H-L test: p= 0.850)		
Sound levels	0.98	0.947 – 1.014
Economical benefits (no/yes)	0.70	0.348 – 1.425
Age (years)	**1.03**	**1.017 – 1.044**
Gender (male/female)	1.18	0.821 – 1.704
Diabetes, (H-L test: p= 0.844)		
Sound levels	1.00	0.917 – 1.093
Economical benefits* (no/yes)	-	-
Age (years)	**1.07**	**1.030 – 1.106**
Gender (male/female)	0.69	0.282 – 1.703
High blood pressure, (H-L test: p= 0.226)		
Sound levels	1.01	0.955 – 1,062
Economical benefits (no/yes)	0.15	0.019 – 1.195
Age (years)	**1.06**	**1.033 – 1.078**
Gender (male/female)	1.27	0.955 – 1.062

(Table 7.39 continued)	OR	95% CI
Tinnitus, (H-L test: p= 0.437)		
Sound levels	0.94	0.848 – 1.038
Economical benefits (no/yes)	0.90	0.095 – 8.418
Age (years)	1.03	0.993 – 1.063
Gender (male/female)	1.26	0.474 – 3.359
Hearing impairment, (H-L test: p= 0.499)		
Sound levels	1.01	0.939 – 1.095
Economical benefits (no/yes)	0.38	0.043 – 3.306
Age (years)	**1.06**	**1.027 – 1.095**
Gender (male/female)	0.60	0.261 – 1.371
Cardiovascular disease, (H-L test: p= 0.023)		
Sound levels	0.98	0.914 – 1.054
Economical benefits (no/yes)	0.39	0.045 – 3.262
Age (years)	**1.06**	**1.030 – 1.090**
Gender (male/female)	0.61	0.293 – 1.268
Migraine, (H-L test: p= 0.016)		
Sound levels	0.93	0.830 – 1.037
Economical benefits* (no/yes)	-	-
Age (years)	0.98	0.942 – 1.010
Gender (male/female)	**13.2**	**1.704 – 101.857**

*no variation, i.e. none of the respondents who benefited economically had reported this chronic disease or symptom

Psychological distress was, as described above, measured with the GHQ-score, which was a continuous scale and therefore not suitable for binary logistic regression. The GHQ-score was re-calculated according to Goldberg to make it possible to explore the relationship between sound levels and psychological distress [Goldberg]. The variable was dichotomized into "not psychologically distressed" and "psychologically distressed", using the cut-off point 2 or above for the latter. The dichotomized variable was used as the dependent variable in a binary logistic regression. Also the stress score and the variables measuring sleep quality were dichotomized for the same purpose. An overview is shown in table 7.40.

Table 7.40: dependent variables in binary logistic regressions

	Definition of yes	n	
		No	Yes
GHQ	2 or above on the GHQTOT_G	532	185
Stress-score	0.01 or higher on the stress-score	429	227
Falling asleep	Difficulties to fall asleep once a month or more often	495	230
Sleep interruption	Interrupted in the sleep once a month or more often	539	186

Sound levels (continuous scale), economical benefits (no/yes), age (continuous scale) and gender (male/female) were entered simultaneously as independent variables into a binary logistic regression (table 7.41). Levels of sound from wind turbines did not influence psychological distress, stress or difficulties to fall asleep. Respondents that did not benefit economically, were older and were females more often had trouble to fall asleep than others. However, interruption in the sleep was associated with sound levels. An increase in sound levels correlated with an increased risk for being interrupted in the sleep. Respondents who benefited economically from wind turbines were less likely to be interrupted in the sleep than respondents who did not benefit economically.

Table 7.41: relationship between sound levels from wind turbines and psychological distress/sleep quality (binary logistic regression)

	OR	95% CI
GHQ (<2/>2), (H-L test: p= 0.965)		
Sound levels	1.02	0.992 – 1.057
Economical benefits (no/yes)	0.74	0.413 – 1.335
Age (years)	0.99	0.992 – 1.001
Gender (male/female)	1.12	0.784 – 1.584
Stress score(≤0/≥0.01), (H-L test: p=0.032)		
Sound levels	1.01	0.979 – 1.041
Economical benefits (no/yes)	0.61	0.345 – 1.068
Age (years)	**0.98**	**0.969 – 0.992**
Gender (male/female)	1.32	0.828 – 1.635
Falling asleep (<once a month/≥once a month), (H-L test: p= 0.366)		
Sound levels	0.99	0.965 – 1.026
Economical benefits (no/yes)	**0.52**	**0.274 – 0.970**
Age (years)	**1.02**	**1.005 – 1.028**
Gender (male/female)	**1.47**	**1.053 – 1.059**
Interrupted in the sleep (<once a month/≥once a month, (H-L test: p= 0.025)		
Sound levels	**1.03**	**1.000 – 1.066**
Economical benefits (no/yes)	**0.45**	**0.236 – 0.839**
Age (years)	1.00	0.985 – 1.008
Gender (male/female)	1.07	0.750 – 1.513

The only measurement of impaired health that was found to increase statistically significant with increasing levels of exposure was interruption in the sleep. It was however not clear which sound source caused interruption in the sleep; it could as well be road traffic sound as sound from wind turbines. It was also of interest to find out at what sound levels the respondents reported interruption in the sleep. A new logistic regression was therefore carried out, now including background sound levels (Lden). Respondents with sound levels from wind turbines below 30 dBA outside their dwelling were chosen as controls. The result show that the odds for being interrupted in the sleep was statistically significantly higher among respondents exposed to levels above 45 dBA than for the control group when adjusted for age, gender and economical benefits from wind turbines (table 7.42). There was a relationship between sleep interruption and levels of background sound: an increase in background sound levels predicted an increase in proportion of respondents reporting having been interrupted in their sleep once a month or more frequently.

Table 7.42: relationship between sound levels from wind turbines and interruption in the sleep (binary logistic regression)

	OR	95% CI
Interrupted in the sleep (<once a month/≥once a month, (H-L test: p= 0.819)		
Sound levels		
<30	1.00	
30 – 35	1.36	0.836 – 2.210
35 – 40	1.54	0.915 – 2.590
40 – 45	1.83	0.976 – 3.438
>45	**2.98**	**1.347 – 6.597**
Background sound (Lden)	**1.04**	**1.018 – 1.059**
Economical benefits (no/yes)	**0.47**	**0.238 – 0.928**
Age (years)	1.00	0.983 – 1.007
Gender (male/female)	1.05	0.739 – 1.503

The same finding is illustrated in figure 7.3; only respondents that did not benefit economically from the wind turbines were included (no adjustments for background sound levels). Less than 30% of the respondents reported that they were interrupted in their sleep by sound once a month or more often. However, among respondents in the group of more than 45 dBA, 48% reported sleep interruption. It has to be noted that the confidence interval is large due to a small number of respondents in that group (n = 21). The findings should therefore be treated with caution.

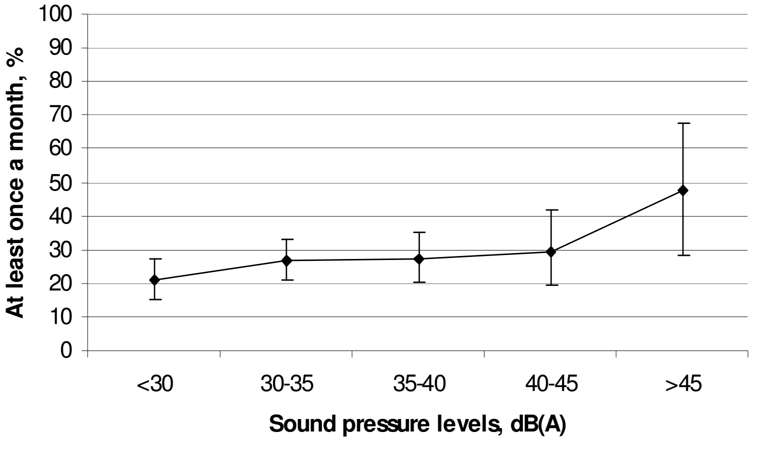
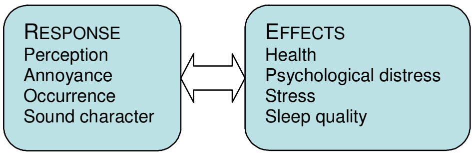


Figure 7.3: relation between levels of wind turbine sound and reports of sleep interruption caused by sound; only respondents who did not benefit economically from wind turbines (with 95% confidence intervals)

The respondents had an opportunity to report the noise source that interrupted their sleep; 244 respondents mentioned one or more sources. Road traffic was mentioned 93 times and wind turbines 36 times. Respondents that had specified wind turbines as a noise source for sleep interruption were found in all of the five exposure groups.

7.10 Relationships between response to wind turbine sound and effects



Relationships between diseases/health symptoms and annoyance with wind turbine noise were also tested with binary logistic regression. The same procedure as described above for exploring relations between sound levels and health effects were used.

No association between annoyance due to wind turbine noise (5-point scale from "Do not notice" to "Very annoyed") outdoors and chronic disease in general was found (table 7.43). However, diabetes was statistically significant related to noise annoyance, also when adjusted for age, gender, economical benefits from wind turbines and sound levels.

Table 7.43: relationship between annoyance due to wind turbine sound and chronic diseases

	OR	95% CI
Chronic disease (H-L test: p=0.951)		
Annoyance (5-point scale)*	1.00	0.826 – 1.208
Diabetes (H-L test: p=0.672		
Annoyance (5-point scale)*	**1.58**	**1.063 – 2.350**
High blood pressure (H-L test: p=0.194)		
Annoyance (5-point scale)*	0.88	0.653 – 1.186
Tinnitus (H-L test: p=0.667)		
Annoyance (5-point scale)*	0.84	0.465 – 1.505
Hearing impairment (H-L test: p=0.956)		
Annoyance (5-point scale)*	1.14	0.772 – 1.680
Cardiovascular disease (H-L test: p<0.05)		
Annoyance (5-point scale)*	0.97	0.668 – 1.408
Migraine (H-L test: p=0.549)		
Annoyance (5-point scale)*	1.22	0.714 – 2.068

*Adjusted for age, gender, economical benefits from wind turbines and sound levels.

The stress score, difficulties to fall asleep and sleep interruption were associated with noise annoyance due to wind turbines (table 7.44). Respondents that were annoyed by wind turbine sound also had higher stress scores, more often difficulties to fall asleep and were more often interrupted in their sleep by sound.

Table 7.44: associations between annoyance due to wind turbine sound, and psychological distress (GHQ), stress-score, difficulties falling asleep and sleep interruption

	OR	**95% CI**
GHQ (<2/>2), (H-L test: p= 0.133)		
Annoyance (5-point scale)*	1.07	0.890 – 1.281
Stress score(≤0/≥0.01), (H-L test: p= 0.776)		
Annoyance (5-point scale)*	**1.27**	**1.065 – 1.509**
Difficulties falling asleep (<once a month/≥once a month), (H-L test: p=0.905)		
Annoyance (5-point scale)*	**1.41**	**1.184 – 1.674**
Sleep interruption (<once a month/≥once a month), (H-L test: p=0.613)		
Annoyance (5-point scale)*	**1.78**	**1.486 – 2.142**

*Adjusted for age, gender, sound pressure levels and economical benefits.

The observed association between GHQ-score and stress scoredescribed above called for further exploration of the relationship between noise annoyance and psychological distress. The relationship was therefore modeled in a multiple linear regression, with the objective to use GHQ-score as a continuous variable and hence take advantage of the whole variation. GHQ-score was assigned to be the dependent variable. A statistically significant relationship between annoyance due to wind turbine sound and GHQ-score was found (table 7.45). The variance of GHQ-score that was explained by the model was however low: only 2% (adj R-square 0.02).

Table 7.45: association between GHQ-score and annoyance

	B	SE	Beta	p-value
GHQ-score, adj R-square 0.02				
Annoyance (5-point scale)	**0.29**	**0.113**	**0.11**	**<0.05**

*Adjusted for age, sex, economical benefits from wind turbines and sound levels.

8. Conclusions

8.1 Discussion of results

Several possible exposures from wind turbines were studied: aural as well as visual. Sound was found to be the most annoying of the exposures. The proportion of respondents that could hear wind turbine sound from their dwelling increased logically with increasing sound levels so that more than 80% heard the sound at levels of 35 – 40 dBA and above. The proportion of respondents that reported that they were annoyed by the sound also increased with increasing sound levels. There was no difference in the ability to hear the sound between respondents that benefited economically from wind turbines and those who did not, but there was a clear difference in annoyance between the two groups. Very few people among those who benefited economically reported annoyance with sound from wind turbines. Among those who did not benefit economically, 2% reported that they were rather or very annoyed at sound levels below 30 dBA, 9% at 30 – 35 dBA, 20% at 35 – 40 dBA, 25% at 40 – 45 dBA and 28% at levels above 45 dBA.
The sound levels that were calculated occur when a wind turbine operates at high, though not maximum power (8m/s wind speed at 10 m height in a neutral atmosphere).

It appears that people living close to wind farms in the Netherlands are not quite the same people as the larger group living further away. Respondents living close to wind farms and exposed to higher sound levels more usually have a farm or detached house in a rural and relatively quiet (lower levels of road traffic sound) area, are more often male and have a less negative view on the visual impact of wind turbines. They are relatively young, well educated, work at home and/or are self-employed and have economical benefits from wind turbines. Also, they are healthier (less often high blood pressure, cardiovascular disease and migraine), and they have less difficulty in falling asleep. In short, they may be typified as 'healthy farmers' and/or entrepreneurs who have to earn their living by making use of the land. This may help to explain the different opinions on wind farms, arising from different views on landscape utility and use.
Another reason for the low prevalence of annoyance amongst respondents with an economical benefit may be that they have more control over the wind turbines. A healthy environment "provides safety, opportunities for social integration, and the ability to predict and/or control aspects of that environment" [Taylor]. Respondents that benefit will more usually have control: most or all of them have taken part in the decision to put up the turbines and they can stop them if they want. One respondent remarked that if a turbine close by caused too much noise for him or his neighbour, he stopped the turbine.

Respondents that could see at least one wind turbine from their dwelling were more likely to be annoyed by the sound than those who did not see any wind turbines. When respondents did not see wind turbines, the turbines were either relatively small, *i.e.* distant, or respondents lived in built-up areas. A free sight from the dwelling to one or more of the wind turbines also gives free way for the sound. In these cases the immission levels at the dwelling of the respondent were in accordance with the calculated levels, and not less due to hindrance of the sound propagation. When the sight of the wind farm is blocked, than the sound may be (partly) blocked too, leading to lower sound levels. This may explain the lower levels of annoyance. However, the enhanced probability for annoyance if the wind turbines were visible could also be due to a multimodal effect; the rotating blades of a wind turbine attracting the sight could increase the awareness of the sound and hence also the possibility of noise annoyance.

Respondents in built-up areas were more likely to be annoyed by wind turbine sound than respondents living in rural areas with road traffic, with approximately the same levels of background sound, despite the lower visibility of wind turbines in the built-up areas. This unexpected finding is not easily understood, but could indicate a saturation of audible and visual stimuli that leads to a negative appraisal of exposures from an additional source. It may also be related to an urban feeling that wind turbines disrupt the perceived naturalness and tranquility of the surrounding countryside.

Background sound levels, mostly from road traffic, influenced the possibility to notice sound from wind turbines; the likeliness to hear wind turbine sound decreased if the levels of background sound increased. However, the likeliness of being annoyed by wind turbine sound was not influenced by the levels of background sound. The main source of background sound was road traffic which is different in character from wind turbine sound. The "swishing" character of wind turbine sound was in the study found to be the most annoying of the suggested sound properties. "Swishing" is a description of amplitude modulated sound that is pulsating with the pace of the rotation of the blades. It will supposedly be perceived as separated from the road traffic sound and therefore be valued independently. This separation may also be due to differences in frequency content. The dominant sound (trailing edge noise) from more or less distant wind turbines is in the range of 400 to 1000 Hz, whereas the dominant sound of more or less distant road traffic is the low pitched engine noise at 60 to 80 Hz and the high pitched tyre noise that dominates frequencies above 1000 Hz.
Finally, road traffic is quieter at night than in daytime, whereas wind turbines are at night equally noisy or noisier than in daytime. The findings suggest that a noisy environment could make wind turbine sound less easily audible, but once the levels of wind turbine sound can be heard above the road traffic, which is more probable at night, the likeliness for annoyance would be the same as in environments with little road traffic.

The probability of being disturbed in the sleep by sound increased with increasing levels of wind turbine sound and of background sound. The odds for being disturbed in the sleep by sound at least once a month were significantly higher at levels of wind turbine sound above 45 dBA than in the control group (<30 dBA). Other measurements of effects on health and well-being that were included in the study were not associated with sound levels as such, but with annoyance with the sound. Respondents who reported that they were annoyed by wind turbine sound were more likely to also be psychologically distressed, reporting symptoms of stress and having difficulties to fall asleep. It appears that these symptoms occur when people are annoyed, but it does not matter at what sound level this annoyance occurs. The study design does not allow conclusions on what is the cause and what is the effect. A plausible explanation of the observed association is that wind turbine sound leads to annoyance for some people; annoyance that in turn possibly hinders psycho-physiological restoration and increases the level of stress. However, it can not be excluded that some people that are under stress or strain for other reasons than wind turbine sound more easily react negatively when exposed to the sound and hence become annoyed. Further studies will be needed to distinguish between the two directions of cause and effect. Also the relationship between diabetes and annoyance should be further investigated.

Annoyance with wind turbine sound was associated with a negative attitude towards the wind turbines, especially with regard to the impact on the landscape scenery. Also when the turbines were judged by opposite pairs of descriptors, the descriptors connected to the visual aspect, for example "ugly" and “natural”, formed a clear group with a high correlation between the different visual descriptors. The judgments of the living environment were also more negative among respondents that were annoyed by the sound than among others.

8.2 Comparison with annoyance from other noise sources

Miedema *et al* have analyzed noise annoyance from transportation noise sources [Miedema]. For air, road and rail traffic it was shown that the dose-response relations, between noise level (L_{den}) and percentage highly annoyed respondents (%HA), can be written as second power polynomials,[1] assuming zero severe annoyance at sound levels below 42 dBA. These relations can be compared with the percentages highly (or very) annoyed by wind turbine sound in this study, either for all respondents or respondents that did not benefit economically (see tables F1 and F2 in Appendix F).[2]

For this comparison, the sound power level used to calculate the immission level due to wind turbines (at 8 m/s 10-m wind speed in a neutral atmosphere) must be transformed to a sound power level characteristic for L_{den}. With an expected accuracy of 2 dB or better this transformation is $L_{W,den} – L_{W,8m/s}$ = 4.7 dB ([Van den Berg 2008], see section 4.3.2).

Results from this study have been plotted in Figure 8.1 together with the curves from Miedema *et al*. The bars at the percentages measured in this study denoet the interval wherein the true percentage is expected to lie with a 95% certainty. The decrease in annoyance at high levels of wind turbine sound is in part due to a higher percentage of respondents that benefit from the turbines. This decrease also occurs for respondents without benefits, but the percentage at the highest value of Lden is determined by only 3 respondents and is thus not a statistically reliable number as demonstrated by the wide confidence interval.

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[1] For air, road and rail traffic it was shown that the dose-response relations, between noise level (L_{den}) and percentage highly annoyed respondents (%HA), can be written as:

- $\%HA = -0.02\cdot(L_{den} - 42) + 0.0561\cdot(L_{den} - 42)^2$ for aircraft noise;
- $\%HA = 0.24\cdot(L_{den} - 42) + 0.0277\cdot(L_{den} - 42)^2$ for road traffic noise;
- $\%HA = 0.28\cdot(L_{den} - 42) + 0.0085\cdot(L_{den} - 42)^2$ for rail traffic noise.

[2] The percentages in Appendix F are standardized acoording to the procedure described by Miedema and therefore differ from the percentages given in chapter 7 (tables 7.25 and 7.26).

From figure 8.1 it appears that wind turbine sound is relatively annoying: at every sound level respondents were more annoyed from modern wind turbines than people generally are from transportation noise sources. The results from this study thus confirm the conclusion from a previous Swedish study [Pedersen *et al* 2004] that wind turbine sound is more annoying than road traffic sound.

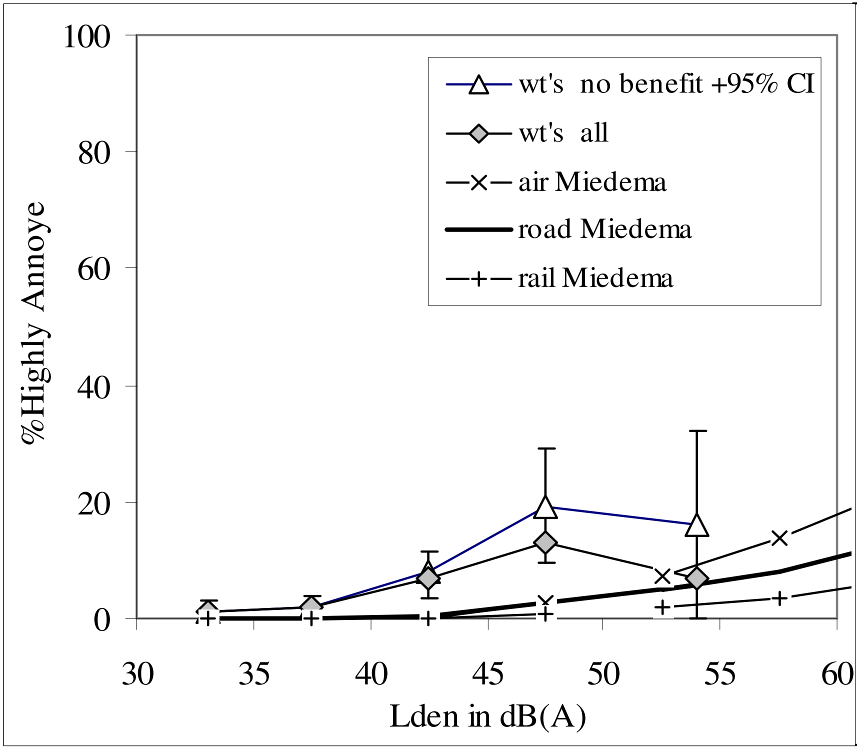

Figure 8.1: relation between sound level Lden and percentage highly annoyed residents exposed to that sound, for three transportation noise sources and for wind turbines; the relation is given for all respondents and for those that have no economical benefit from a wind turbine.

Bars denote 95% confidence interval for non-benefitters.

For road traffic noise also the results of this study can be compared to the standardized percentage of highly annoyed. As is shown in Appendix H the standardized percentages for raod traffic noise lie within the 95% confidence intervals of the percentages in this study. Thus, as far as noise annoyance is concerned the respondents in this study do not differ significantly from the standard population.

8.3 Main conclusions

The analysis results are summarized below.

With respect to hearing wind turbines:

- The probability to hear wind turbines increased with increasing levels of wind turbine sound, irrespective of the appreciation of the sound by respondents.
- Not having wind turbines visible from the dwelling and high levels of background (road traffic) sound decreased the probability of hearing wind turbine sound, though the influence of background sound is small.
- Wind turbines were perceived as louder when the wind was blowing from the wind turbine towards the dwelling, and less loud vice versa.
- Wind turbines were perceived as louder when the wind was strong and less loud with a weak or no wind. However, more respondents thought it was louder than less loud at night, even though at night wind speeds are on average lower.

With respect to annoyance from wind turbine sound

- Of the exposures from wind turbines, noise was the most annoying.
- The probability of being annoyed by wind turbine sound increased with increasing levels of wind turbine sound.
- The most common description of the wind turbine sound was swishing/lashing; a description that was associated with noise annoyance: annoyance is more probable for respondents that gave this description than for those who did not.
- Benefiting economically from wind turbines, not having wind turbines visible from the dwelling and living in a rural area with a main road (in comparison with a built-up area) decreased the probability of being annoyed by wind turbine sound.
- Although the presence of background sound from road traffic made wind turbine sound less noticeable, higher levels of background sound did not reduce the probability of being annoyed.
- Annoyance with wind turbine noise was associated with a negative attitude towards wind turbines in general and the impact of wind turbines on the landscape.

With respect to other health effects associated with wind turbines:

- The risk for sleep interruption by noise was higher at levels of wind turbine sound above 45 dBA than at levels below 30 dBA.
- Annoyance with wind turbine noise was associated with psychological distress, stress, difficulties to fall asleep and sleep interruption.

8.4 Recommendations

Several conclusions suggest that practical measures may either increase or decrease the negative impact of wind farms.

Perhaps the main finding is that wind turbine sound is relatively annoying, more so than equally loud sound from aircraft or road traffic. A swishing character is perceived by most respondents, indicating that this is an important characteristic of wind turbine sound. Sound should therefore receive more attention in the planning of wind farms, and (more) sound mitigation measures must be considered.

At the same time it can be concluded that people that benefit from wind turbines are much less or not at all annoyed. This is true even though they notice the sound equally well as all other respondents do and both groups use the same characteristics to describe it. However, the groups differ in personal characteristics: those benefiting are more usually ‘healthy farmers’, have a more positive view on the visual impact of wind turbines and are relatively young and well educated. Respondents that benefit from the wind turbines are less annoyed in spite of living in a rural area and closer to wind farms -and thus experiencing higher wind turbine sound levels. Several factors may explain this relative absence of annoyance: the more positive opinion on wind farms -arising from different views on landscape utility and use, the actual financial benefit, and the sense of control making it possible to reduce temporarily the impact if wanted. This may lead to possibilities to mitigate annoyance: residents may be given a sense of control and some benefits, and could perhaps learn to share other views on (some) landscapes.

It is difficult to separate the visual from the acoustic impact, because they are so closely related: when turbines are closer and bigger they are usually better audible. However, when wind turbines are less visible they are less easily noticed by their sound and cause less annoyance. Perhaps the same is true when there is less visual contrast between wind turbines and their environment. Some respondents have remarked in the questionnaires that wind turbines make the landscape more dynamical, or they serve as handy indicators of wind direction and speed. This perceived ‘appropriateness’ with respect to the environment may thus help to cause less impact.

When there is more background sound from road traffic, wind turbine sound is –as one would expect- less easily noticeable. However, the results show that road traffic noise does not seem to reduce the annoyance due to a wind farm. This may be due to the different characteristics of both sounds: road traffic is usually less loud in night time, whereas wind turbines are not. Also, the swishing character and pitch of wind turbine sound may make the sound discernible even in moderate to high levels of road traffic noise. As it has been proposed several times to construct wind farms in the Netherlands close to motorways because the motorway noise would ‘mask’ the wind turbine noise, such a masking capability is an important issue. In this study no empirical evidence has been found for this point of view. This needs further investigation.

9. Acknowledgements

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Four (former) students from the Faculty of Mathematics and Natural Sciences of the University of Groningen have cooperated in this project. Eildert Slim collected the information on sound production of wind turbines. Lianne Schuiling designed and wrote the text for the website for this project. Rowan Rossing, just finishing his study, designed a software application that enabled the calculation of visual and aural exposure for the study group from all Dutch wind turbines. Jan Oudelaar already had finished his study and was appointed as our GIS expert who did all the selection on turbines and addresses.

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Appendices

Appendix A: Questionnaire text

STUDY OF THE PERCEPTION OF THE LIVING ENVIRONMENT

1. On what date do you fill in this questionnaire? (Fill in date: - .. - ..)
2. How many people are there in the household (including yourself)? (Above 18 years: …..; under 18 years: ….)
3. How many years have you lived at this address? (….. years)
4. In what type of residence do you live? *(more than one answer possible)* (farm, detached dwelling, owned apartment, rented apartment, summerhouse → 6))
5. Where did you live before you moved to this address? (always lived here, in the countryside, in a small town, in a city)
6. How satisfied are you with your living environment? (very satisfied, satisfied, not so satisfied, not satisfied, not at all satisfied)
7. Have there been any changes *for the better* in your living environment during the last years? (no → 8, yes). *If yes, which positive changes have occurred?*
8. Have there been any changes *for the worse* in your living environment during the last years? (no → 9, yes). *If yes, which negative changes have occurred?*
9. To what extent do you *agree* or *disagree* with the statements below about your dwelling and your living environment? (do not agree at all, do not agree, neither agree or disagree, agree, totally agree)
   I spend a lot of time at home if possible.
   When outside on a calm summer morning, I can hear only bird song and other nature sounds.
   Sound from agricultural machinery is a natural part of my living environment.
   It is not very important what my living environment looks like, as long as it is functional.
   I live in a place where I can restore myself and gain strength.
   I have renovated major parts of my dwelling since I moved in.
   The area where I live is suitable for economical growth.
   Background sounds from road traffic are almost always present outdoors.
   I feel a sense of community with people living in this area.
   I like to personalize my dwelling.
   I have many friends in the neighbourhood that I socialize with.
   It is never really quiet in the area.
   I am concerned about keeping the garden/the balcony tidy.
10. Below are a number of items that you may notice or that could annoy you when you spend time ***outdoors*** at your dwelling. Could you indicate whether you have noticed these or whether these annoy you? (do not notice, notice but not annoyed, slightly annoyed, rather annoyed, very annoyed)
    Odour from industries
    Odour from manure
    Flies and/or gnats
    Sound from agricultural machinery
    Airplane sound

Road traffic sound
Railway sound
Sound from wind turbines
View on power lines/pylons
View on factories
View on wind turbines
View on busy road
Other, namely: *(please indicate what)*

11. Below are a number of items that you may notice or that could annoy you when you spend time ***indoors*** at your dwelling. Could you indicate whether you have noticed these or whether these annoy you? (do not notice, notice but not annoyed, slightly annoyed, rather annoyed, very annoyed)
    (same items as in 10.)
12. How would you describe your sensitivity to the environmental factors below? (not sensitive at all, hardly sensitive, slightly sensitive, rather sensitive, very sensitive)
    Air pollution
    Odours
    Noise
    Littering

The next questions are about sources of possible nuisance in your living environment

13. In your living environment there are possibly one or more busy roads. What is your opinion on the impact of busy roads on the landscape scenery? (very positive, positive, neither positive nor negative, negative, very negative) *If (very) positive of (very) negative, in what way do you think the impact is positive or negative?*
    …………………
14. To what extent are you affected by busy roads in your living environment? Please indicate for each item whether you notice it or are annoyed by it. (do not notice, notice but not annoyed, slightly annoyed, rather annoyed, very annoyed)
    Sound indoors
    Sound outdoors
    The movement of the vehicles
    Odor (exhaust gases) indoor
    Odor (exhaust gases) outdoor
    Changed view
    Other, namely: *(please indicate what)*
15. ***How often*** are you annoyed by the factors mentioned in 14 ((almost) never, at least once in the past year, at least once a month, at least once a week, (almost) daily)
    (same items as in 14)
16. Can you see a busy road from your residence or garden/balcony? (no, yes)
17. Can you hear the sound of busy roads from your residence or garden/balcony? (yes, no → 21)
18. To what extent are you annoyed by the sound of road traffic when you are ***outdoors*** at your dwelling? Please encircle a number on the scale between 0 and 10; if you are not annoyed at all you encircle a 0, if you are

extremely annoyed you encircle a 10. If the perceived annoyance is in between, please encircle the most appropriate number

I am not at all annoyed 0 – 10 I am extremely annoyed

19. To what extent are you annoyed by the sound of road traffic when you are ***indoors***? Please encircle a number on the scale between 0 and 10; if you are not annoyed at all you encircle a 0, if you are extremely annoyed you encircle a 10. If the perceived annoyance is in between, please encircle the most appropriate number

    I am not at all annoyed 0 – 10 I am extremely annoyed
20. If you are affected by busy roads, which type of road traffic do you find most intrusive? *(more than one answer possible)* (Cars, trucks, motorbikes, scooters/mopeds, tractors)
21. In your area there are possibly wind turbines. What is your opinion on the impact of wind turbines on the landscape scenery? (very positive, positive, neither positive nor negative, negative, very negative). *If (very) positive of (very) negative, in what way do you think the impact is positive or negative?* …………………
22. To what extent are you affected by wind turbines in your living environment? Please indicate for each item whether you notice it or are annoyed by it in your living environment. (do not notice, notice but not annoyed, slightly annoyed, rather annoyed, very annoyed)

    Blinking shadows indoors
    Moving shadows outdoors
    Sound from rotor blades
    Movement of rotor blades
    Changed view
    Vibrations
    Other, namely: *(please indicate what)*
23. ***How often*** are you affected by the factors in question 22? ((almost) never, at least once in the past year, at least once a month, at least once a week, (almost) daily)

    (same items as in 22)
24. Can you hear the sound of wind turbines from within your house or from your garden/balcony? (yes, no → 29)
25. How would you describe the sound of the wind turbines? *(you can tick more than one answer category)*

    A pure tone
    Thumping/throbbing
    Swishing/lashing
    Whistling/screeching
    Rustling
    Scratching/squeaking
    A low frequency/low pitched sound
    Resounding
    Other, namely: *(please indicate what)*
26. To what extent are you annoyed by the sound of wind turbines when you are **outdoors** at your dwelling? Please encircle a number on the scale between 0 and 10; if you are not at all annoyed you encircle a 0, if you are extremely annoyed you encircle a 10. If the perceived annoyance is in between, please encircle the most appropriate number

    I am not at all annoyed scale 0 – 10 I am extremely annoyed

27. To what extent are you annoyed by the sound of wind turbines when you are in**doors**? Please encircle a number on the scale between 0 and 10; if you are not at all annoyed you encircle a 0, if you are extremely annoyed you encircle a 10. If the perceived annoyance is in between, please encircle the most appropriate number
    I am not at all annoyed scale 0 – 10 I am extremely annoyed
28. Are there conditions when the sound of these wind turbines is more distinct? (I hear it less loud then usual, I hear it louder then usual, it makes no difference, I do not know whether it makes a difference)
    When the wind blows from the turbine towards my dwelling
    When the wind blows from my dwelling towards the turbine
    When there is a weak/no wind
    When the wind is strong
    On warm summer evenings
    At night time
    When I see the wind turbines sideways
    Other, namely: *(please indicate what)*
29. Are you a (co-) owner of a wind turbine? (no, yes I own one or more turbines, yes I own shares/am a co-owner of wind turbines)
30. Have you received any financial or economical benefit of the construction of wind turbines in your living environment? (no, yes) *If yes, can you clarify your answer? ……*
31. What is your general opinion on wind turbines? (very positive, positive, neither positive nor negative, negative, very negative)
32. What is your opinion on the statements below about wind turbines? Please encircle the number that corresponds best to your opinion: 1 through 5 for each of the following pairs:
    efficient – inefficient
    environmentally friendly – not environmentally friendly
    pretty – ugly
    necessary – unnecessary
    inviting – repulsive
    natural – unnatural
    annoying - blends in
    dangerous – harmless
33. Can you see a wind turbine from your dwelling or your garden/balcony? (yes, no; if no → 34) *If yes, how many wind turbines can you see? (f*rom my dwelling:….. ; from my garden/balcony: …..)
34. If there are wind turbines in your environment, is your bedroom situated at the side of the house where those wind turbines are? (no, yes)
35. If there is a busy road in your environment, is your bedroom situated at the side of the house where the busy road is? (no, yes)
36. On what floor is your bedroom? (ground level, …. floor)

The next questions are about your health and the way you perceive your health

37. Do you have any long term/chronic disease? (no → 38, yes). *If yes, which chronic disease do you have?* (diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, migraine, other *viz:*)

38. Have you been troubled by the following symptoms during the last months? ((almost) never, at least once a month, at least once a week, (almost) daily)
    - Headache
    - Undue tiredness
    - Pain and stiffness in the back, neck or shoulders
    - Feeling tense or stressed
    - Depressivity
    - Not very sociable, wanting to be alone
    - Irritable
    - Resigned
    - Fearful
    - Concentration problems
    - Nausea
    - Vertigo
    - Mood changes
    - Other, namely: *(please indicate what)*
39. Do you have health complaints that you think are related to environmental factors? (no → 40, yes). *If yes, to which environmental factors do you relate them? (for example noise, odour, radiation, pollution) (more than one answer possible)*
    If you have complaints that you think are related to environmental factors, did you consult a doctor for these complaints? (no, yes)
40. How often have you had difficulties falling to sleep in your home? ((almost) never, at least once in the past year, at least once a month, at least once a week, (almost) daily)
41. How often do you sleep with your window ajar or open? ((almost) never, sometimes, often, always)
42. How often is your sleep interrupted by sound? ((almost) never, at least once in the past year, at least once in the past month, at least once in the past week, (almost) daily). *If your sleep is ever interrupted, which sound sources are involved? ……..*
43. How have you been feeling in the morning during the last months? Please encircle a number between 0 and 10 on both scales below.
    Very rested scale 0 – 10 very sleepy
    Very relaxed scale 0 – 10 very tense

We would like to know how well you feel and what complaints you have had **in the past few weeks**. Please answer the questions below. Remember that this concerns only the complaints of this moment in time or of the last few weeks, **not** the complaints you have ever had **in the past**. (answers are: not at all, no more than usual, rather more than usual, much more than usual).

44. Have you lost much sleep over worry lately?
45. Did you feel constantly under strain lately?
46. Have you been able to concentrate on whatever you're doing lately?
47. Did you feel you were playing a useful part in things lately?
48. Have you been able to face up to your problems lately?

49. Did you feel capable of making decisions (about things) lately?
50. Did you feel you couldn't overcome your difficulties lately?
51. Did you feel reasonably happy lately, all things considered?
52. Have you been able to enjoy your normal day-to-day activities lately?
53. Did you feel unhappy and depressed lately?
54. Have you been losing confidence in yourself lately?
55. Have you been thinking of yourself as a worthless person lately?
56. How would you generally rate the quality of your life (how satisfied are you with your life, all things considered)? Please encircle a number between 0 and 10 on the scale below.
    Best possible quality of life scale 0 – 10 lowest possible quality of life
57. How would you rate your quality of life if there were no busy roads in your neighbourhood?
    Best possible quality of life scale 0 – 10 lowest possible quality of life
58. How would you rate your quality of life if there were no wind turbines in your neighbourhood?
    Best possible quality of life scale 0 – 10 lowest possible quality of life
59. What is your sex? (male, female)
60. In what year were you born? (in …..)
61. What is the highest education level you completed? (lower general or primary education or part thereof, lower vocational education, secondary general education, secondary vocational education, higher vocational education, university education)
62. What was your main occupation the last half year? (household work, working at home, employed, parental leave, sick leave, retired, study, currently unemployed, disablement insured, other *viz*)
63. What are your normal working hours? (daytime, both night- and dayshift, 2-3 shift, only nights, other *viz*)
64. At which hours are you usually at home? (in daytime 7 – 19 hours: from … to … hours and from … to … hours; in evening and night time (19 – 7 hours): from … to … hours and from … to … hours)

If you would like to add a remark that you think might be of interest for this study and not sufficiently addressed in this questionnaire, you can do so below. (followed by open space)

This is the end of the questionnaire. Many thanks for your cooperation.

Give your e-mail address here if you want to receive the results of this study.

Appendix B: Available spectral sound power data

Manufacturer	type	version	power kW	hub height	diameter	mode	sound emission per octave band at V10 (m/s)	31.5Hz	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	8000Hz	sum
Bonus	Bonus 1300	Bonus 1300	1300	66m	62m	19 rpm	7		81.8	88.8	90.8	92.1	90.7	90.3	87.9	82.8	98.3
Bonus	Bonus MKIV	Bonus 600/44-40	600				7		76.2	86.2	92.3	93	89.8	88	87.4	89.3	98.5
Enercon	E-40	E-40/6.44	600	50m	44m		8		83	89	91	95	97	89	82	75	100.6
Enercon	E-40	E-40/6.44	600	65m	44m		9.2	73.8	83	88.5	93	96.9	95	89.3	83.9	72.9	100.8
Enercon	E-66/18.70		1800					71	82	92	94	98	98	93	88	4.9	102.9
Enercon	E-70	E-70 E4	2000	85m	71m		8		85	93.5	97.2	96	91.1	86.6	81.7	75.7	101.4
Enercon	E-70	E-70 E4	2300	85m	71m	mode 2	8		86.5	94.8	97.8	96.7	94.3	90.4	83.6	77.1	102.6
Enron	TW 1.5s	TW 1.5s	1500	80m	70m	22 rpm	8		86	91	96	97	98	94	88	75	103,0
Lagerwey	LW50		750				7		80	90	92	93	94	94	94		100.9
NedWind	NedWind 40	NedWind 40	500	39m	40m		7		72	92	93	98	99	89	85	75	102.8
Neg Micon	NM52	NM52/900	900	40m	52m	22,4 rpm	7		75.7	90.3	92.3	93.9	90.6	89	84.5	79.7	98.8
Neg Micon	NM52	NM52/900	900	70m	52m	22 rpm	8		78	89	94	96	94	92	91	83	101.1
Neg Micon	NM54	NM54/950	950	46m	54m	22 rpm	7	68.2	73.4	81.4	93.9	95.8	95.1	95.3	90.2	85.1	101.6
Nordex	N90	N90	2300	100m	90m	16,9 rpm	8.7		82	95	95	95	96	97	95	89	103.5
Nordtank	NTK37	NTK37/500	500	42,5m	37m		4		73.2	81.8	86.6	89.8	85.8	84.5	83.3	75.2	94,0
Nordtank	NTK37	NTK37/500	500	42,5m	37m		4		73.9	82.5	87.3	90.5	86.5	85.2	84	75.9	94.7
Nordtank	NTK37	NTK37/500	500	35m	37m		8		76.3	84.9	89.7	92.9	88.9	87.6	86.4	78.3	97.1
Nordtank	NTK43	NTK43/600	600	40m	43m		7.8		77.1	84	91.7	94.5	90.2	87.7	85.5	78.7	98.2
Vestas	V39	V39-500kW	500	40.5m	39m		5.8		79	87	89	91	89	88	81	66	96.2
Vestas	V39	V39-500kW	500	40.5m	39m		8		81	89	91	93	91	90	83	68	98.2
Vestas	V44	V44-600kW	600	55m	44m		8		72	78	85	91	94	92	91	90	99,0
Vestas	V44	V44-600kW	600	55m	44m		8		78.6	86.5	88.8	92.6	94	91.6	88.4	74	98.9
Vestas	V44	V44-600kW	600	41m	44m	Optitip	8		78.1	85.9	89.4	93.7	94.8	92.4	86.8	74.8	99.5
Vestas	V47	V47-660 kW	660	55m	47m		8		78	86	90	95	97	93	88	69	100.9
Vestas	V47		660				8		78.2	86.1	89.8	95.2	97	92.9	87.9	69.2	100.9
Vestas	V52	V52-850kW	850	65m	52m		8		79	87	93	97	95	92	86	75	101.1
Vestas	V66	V66-1650kW	1650	70m	66m	19 rpm	8		84	92	95	98	98	96	90	78	103.6
Vestas	V80	V80-2,0MW	2000	60m	80m		8		82	88	94	95	95	93	90	73	101,0
Vestas	V80	V80-2,0MW	2000	68m	80m	101dB(A)	8		82	89	94	96	94	93	86	69	100.9
Vestas	V80	V80-2,0MW	2000	80m	80m		8		82.3	89.6	94.8	96.2	91.8	93.5	86.7	69.6	101,0
Vestas	V90	V90-3.0MW	3000	75m	90m		5	76.3	83.3	88.7	94	97	96.6	92.6	88.6	85.7	102,0
Vestas	V90	V90-3.0MW	3000	105m	90m		8		92.5	94.5	97.5	100.5	101.5	101.5	100.5		107.8
Vestas	V90	V90-3.0MW	3000	75m	90m		7	83.6	91.3	95	100.5	103.3	102.9	99.5	95.7	95.4	108.6
Vestas	V90		2000				8		88.3	93.6	95.9	97.2	97.1	96.1	93.1	79.1	103.7
Windmaster	750-E (750kW)		750	45m				75	81	87	91	95	97	89	78		100.4

Appendix C: Sound power levels and wind speed

Wind speeds are at 10 m height in a neutral atmosphere and a standard ground roughness

Manufacturer	type	version	power	hub height	diameter	mode	sound power level in dB(A)								
			kW	m	m		3m/s	4m/s	5m/s	6m/s	7m/s	8m/s	9m/s	10m/s	11m/s
Bonus	Bonus 1300	Bonus 1300	1300	66	62	15 rpm					93,8				
Bonus	Bonus 1300	Bonus 1300	1300	66	62	19 rpm					98,8				
Bonus	Bonus 1300	Bonus 1300	1300	50	62	19 rpm						98,8			
Bonus	Bonus MKIV	Bonus 600/44-40 MKI'	600				90,1	90,7	92,4	95,9	98,2	99,1	99,7	100,3	100,9
Enercon	E-40	E-40/6.44	600	50	44			97	98	99	100	100	101	101	
Enercon	E-40	E-40/6.44	600	50	44					97	98,5	99,5			
Enercon	E-40	E-40/6.44	600	46	44							99,2		100,5	
Enercon	E-40	E-40/6.44	600	50	44							99,3		100,6	
Enercon	E-40	E-40/6.44	600	58	44							99,5		100,8	
Enercon	E-40	E-40/6.44	600	65	44							99,6		100,8	
Enercon	E-40	E-40/6.44	600	75	44							99,9		100,8	
Enercon	E-40	E-40/6.44	600	78	44							99,9		100,8	
Enercon	E-66	E-66/20.70	2000							96,5	99	101	102,5	103	
Enercon	E-70	E-70 E4	2000	58	71			90,7	93,6	98,5	100,8	101,9	103	103	
Enercon	E-70	E-70 E4	2000	64	71			90,8	93,6	98,8	100,9	102,1	103	103	
Enercon	E-70	E-70 E4	2000	85	71			91,1	94,1	99,7	101,1	102,5	103	103	
Enercon	E-70	E-70 E4	2000	98	71			91,3	94,6	100	101,2	102,7	103	103	
Enercon	E-70	E-70 E4	2000	113	71			91,4	95,1	100,3	101,4	102,8	103	103	
Enercon	E-70	E-70 E4	2000	85	71					99,1	100,2	101,4	102		
Enercon	E-70	E-70 E4	2300	58	71			90,7	93,6	98,5	101,3	102,9	104,5	104,5	
Enercon	E-70	E-70 E4	2300	64	71			90,8	93,6	98,8	101,4	103,1	104,5	104,5	
Enercon	E-70	E-70 E4	2300	85	71			91,1	94,1	99,7	101,6	103,5	104,5	104,5	
Enercon	E-70	E-70 E4	2300	98	71			91,3	94,6	100	101,7	103,7	104,5	104,5	
Enercon	E-70	E-70 E4	2300	113	71			91,4	95,1	100,3	101,9	103,8	104,5	104,5	
Enercon	E-70	E-70 E4	2300	85	71	mode 2				98,2	100,6	102,6	104	104,4	
Enron	TW 1.5s	TW 1.5s	1500	80	70	11 rpm		100	100	100	100	100			
Enron	TW 1.5s	TW 1.5s	1500	80	70	22 rpm			102	102	103	103	104	104	
Lagerwey	LW18/80		80	25	18						88,9	89,7			
Neg Micon	NM52	NM52/900	900	70	52	15 rpm		93	93	94					
Neg Micon	NM52	NM52/900	900	70	52	22 rpm			98	99	100	101	102	103	
Neg Micon	NM54	NM54/950	950	46	54	15 rpm					95,6				
Neg Micon	NM54	NM54/950	950	46	54	22 rpm					101,6				
Neg Micon	NM54	NM54/950	950	55	54	22 rpm						103,7			
Nordex	N80	N80	2500	80	80		97	98,7	100	100,9	101,7	102,6	103,1	103,8	104,5
Nordex	N90	N90	2300	100	90	16,9 rpm		101	102	103	103	104	104	105	
Nordtank	NTK37	NTK37/500	500	35	37					95,9	96,5	97,1			
Nordtank	NTK37	NTK37/500	500	42,5	37		93	94	96	97	97	97	97		
Nordtank	NTK43	NTK43/600	600	40	43		96,1	96,5	96,9	97,3	97,7	98,1	98,5	98,9	99,3
Repower	MM82	MM82	2000	80	82			95	97,5	100	102	103,5	105	106	106,5
Repower	MM82	MM82	2000	80	82				99	101	102	103	105	105	105

Manufacturer	type	version	power	hub height	diameter	mode	sound power level in dB(A)								
			kW	m	m		3m/s	4m/s	5m/s	6m/s	7m/s	8m/s	9m/s	10m/s	11m/s
Vestas	V39	V39-500kW	500	40.5	39					96,3		97,8			
Vestas	V39	V39-500kW	500	40.5	39					96,3		97,8			
Vestas	V44	V44-600kW	600	55	44			98,1	98,3	98,5	98,7	98,9	99,1	99,3	
Vestas	V44	V44-600kW	600	55	44			98,6	98,8	99	99,3	99,1			
Vestas	V44	V44-600kW	600	41	44	Optitip				98,5	98,7	98,9	99,1		
Vestas	V47	V47-660 kW	660	55	47			99	99	100	100	101	101	102	
Vestas	V52	V52-850kW	850	65	52			97	98	100	101	102	103	104	
Vestas	V66	V66-1650kW	1650	70	66	15 rpm	97	97	97	98	98	98			
Vestas	V66	V66-1650kW	1650	70	66	19 rpm			101	101	101	102	102	102	
Vestas	V80	V80-2,0MW	2000	68	80	101dB(A)		98	100	101	101	101	102	105	
Vestas	V80	V80-2,0MW	2000	68	80	102dB(A)		98	101	102	102	102	103	105	
Vestas	V80	V80-2,0MW	2000	68	80	103dB(A)		98	101	103	103	103	104	105	
Vestas	V80	V80-2,0MW	2000	68	80	104dB(A)		100	103	104	104	104	105	105	
Vestas	V80	V80-2,0MW	2000	68	80	105dB(A)		101	104	105	105	105	105	105	
Vestas	V80	V80-2,0MW	2000	78	80	101dB(A)		94	99,6	100,2	100,7	101	101,9	102,8	104,1
Vestas	V80	V80-2,0MW	2000	78	80	102dB(A)		94,1	99,7	101,2	101,7	102	102,9	103,7	104,3
Vestas	V80	V80-2,0MW	2000	78	80	102,5dB(A)		94,1	99,5	101,7	102,1	102,6	103,5	103,8	104,3
Vestas	V80	V80-2,0MW	2000	78	80	104dB(A)		94,1	99,6	102,7	103,4	104	104,2	103,7	104,3
Vestas	V80	V80-2,0MW	2000	78	80	105,1dB(A)		94,1	99,6	103	104,2	105	104,9	103,8	104,3
Vestas	V80	V80-2,0MW	2000	100	80	101dB(A)		95	99,8	100,3	100,8	101,3	102,3	103,1	104,4
Vestas	V80	V80-2,0MW	2000	100	80	102dB(A)		95	99,9	101,3	101,8	102,3	103,2	103,9	104,6
Vestas	V80	V80-2,0MW	2000	100	80	102,5dB(A)		95	100	101,8	102,2	102,9	103,7	103,9	104,6
Vestas	V80	V80-2,0MW	2000	100	80	104dB(A)		95	100,2	102,7	103,7	104,3	104,1	103,9	104,6
Vestas	V80	V80-2,0MW	2000	100	80	105,1dB(A)		95	100,3	103,3	104,5	105,2	104,2	103,9	104,6
Vestas	V90	V90-3.0MW	3000	65	90	mode 0		96,4	101,5	105,3	107,8	109,1	109,4	108	106,1
Vestas	V90	V90-3.0MW	3000	80	90	mode 0		97	102	105,8	108,2	109,3	109,4	106,7	105,9
Vestas	V90	V90-3.0MW	3000	90	90	mode 0		97,5	102,4	106,1	108,3	109,4	109,2	106,5	105,9
Vestas	V90	V90-3.0MW	3000	105	90	mode 0		98,2	103	106,5	108,6	109,4	109	106,3	105,8
Vestas	V90	V90-3.0MW	3000	65	90	mode 1		96,4	101,5	105,3	107,5	107,8	107,8	107,2	106,1
Vestas	V90	V90-3.0MW	3000	80	90	mode 1		97	102	105,8	107,7	107,8	107,8	106,7	105,9
Vestas	V90	V90-3.0MW	3000	90	90	mode 1		97,5	102,4	106,1	107,8	107,8	107,8	106,5	105,9
Vestas	V90	V90-3.0MW	3000	105	90	mode 1		98,2	103	106,5	107,8	107,8	107,7	106,3	105,8
Vestas	V90	V90-3.0MW	3000	65	90	mode 2		96,4	101,5	105,2	106,8	106,8	106,8	106,8	106,1
Vestas	V90	V90-3.0MW	3000	80	90	mode 2		97	102	105,6	106,8	106,8	106,8	106,8	105,9
Vestas	V90	V90-3.0MW	3000	90	90	mode 2		97,5	102,4	105,8	106,8	106,8	106,8	106,5	105,9
Vestas	V90	V90-3.0MW	3000	105	90	mode 2		98,2	103	106,3	106,8	106,8	106,8	106,3	105,8
Vestas	V90	V90-3.0MW	3000	65	90	mode 3		96,4	101,5	104,4	104,4	104,4	104,4	104,4	104,4
Vestas	V90	V90-3.0MW	3000	80	90	mode 3		97	102	104,4	104,4	104,4	104,4	104,4	104,9
Vestas	V90	V90-3.0MW	3000	90	90	mode 3		97,5	102,4	104,4	104,4	104,4	104,4	104,4	105,2
Vestas	V90	V90-3.0MW	3000	105	90	mode 3		98,2	102,9	104,4	104,4	104,4	104,4	104,4	105,8
Vestas	V90	V90-3.0MW	3000	65	90	mode 4		96,4	101,5	102,8	102,8	102,8	102,8	102,8	102,8
Vestas	V90	V90-3.0MW	3000	80	90	mode 4		97	102	102,8	102,8	102,8	102,8	102,8	102,8
Vestas	V90	V90-3.0MW	3000	90	90	mode 4		97,5	102,2	102,8	102,8	102,8	102,8	102,8	102,9
Vestas	V90	V90-3.0MW	3000	105	90	mode 4		98,2	102,4	102,8	102,8	102,8	102,8	102,8	103,6
Vestas	V90	V90-3.0MW	3000	75	90						108,6				
Vestas	V90	V90-3.0MW	3000	75	90				102						
Vestas	V90	V90-3.0MW	3000	105	90			95	100	105	107	107,6	108	107	107
Vestas	V90		2000					95	100	103	104	104	103	103	103
Vestas	V90		3000					97	102	105,8	108,2	109,3	109,4	106,7	105,9

Appendix D: Sound power data used in calculations

type ID 1 – 28: data from acoustic reports

type ID r1 – r28: data from other wind turbine type with equal nominal electric power

type nr at type ID r1 – r28 equals power in kW

H = hub height; D = rotor diameter

Type ID	Type nr	Manufacturer	31.5	63	125	250	500	1000	2000	4000	8000	H	D
			Hz									m	m
1	Bm250	Bouma	63.1	71.0	80.1	89.7	89.6	92.3	90.7	83.3	72.0	51	--
2	Bo600	Bonus	-99.0	76.2	86.2	92.3	93.0	89.8	88.0	87.4	89.3	40	--
3	Bo1300	Bonus	-99.0	81.8	88.8	90.8	92.1	90.7	90.3	87.9	82.8	66	62
4	Ec600	Enercon	73.8	83.0	88.5	93.0	96.9	95.0	89.3	83.9	72.9	65	44
5	Ec800	Enercon	-99.0	81.7	90.4	94.7	96.7	96.1	94.5	90.4	77.5	--	--
6	Ec1800	Enercon	71.0	82.0	92.0	94.0	98.0	98.0	93.0	88.0	4.9	--	--
7	Ec2000	Enercon	-99.0	82.2	90.9	95.2	97.2	96.6	95.0	90.9	78.0	--	--
8	Ec2300	Enercon	-99.0	86.3	95.2	99.4	99.2	94.6	89.9	85.7	82.2	85	71
9	Er1500	Enron	-99.0	86.0	91.0	96.0	97.0	98.0	94.0	88.0	75.0	80	70
10	Lw80	Lagerwey	-99.0	74.2	82.9	87.2	89.2	88.6	87.0	82.9	70.0	40	18
11	Lw250	Lagerwey	-99.0	83.2	91.9	96.2	98.2	97.6	96.0	91.9	79.0	51	30
12	Lw750	Lagerwey	-99.0	80.0	90.0	92.0	93.0	94.0	94.0	94.0	-99.0	--	--
13	Nw500	NedWind	-99.0	72.0	92.0	93.0	98.0	99.0	89.0	85.0	75.0	39	40
14	NM900	Neg Micon	-99.0	78.0	89.0	94.0	96.0	94.0	92.0	91.0	83.0	70	52
15	NM950	Neg Micon	68.2	73.4	81.4	93.9	95.8	95.1	95.3	90.2	85.1	46	54
16	Nd2300	Nordex	-99.0	82.0	95.0	95.0	95.0	96.0	97.0	95.0	89.0	100	90
17	Nd2500	Nordex	-99.0	90.0	95.0	99.0	99.0	96.0	97.0	92.0	79.0	80	90
18	Nt500	Nordtank	-99.0	76.3	84.9	89.7	92.9	88.9	87.6	86.4	78.3	35	37
19	Nw100	Northwind	-99.0	73.0	81.7	86.0	88.0	87.4	85.8	81.7	68.8	25	19
20	Rp2000	Repower	-99.0	84.2	92.9	97.2	99.2	98.6	97.0	92.9	80.0	80	82
21	Ve500	Vestas	-99.0	79.0	87.0	89.0	91.0	89.0	88.0	81.0	66.0	40.5	39
22	Ve600	Vestas	-99.0	78.6	86.5	88.8	92.6	94.0	91.6	88.4	74.0	55	44
23	Ve660	Vestas	-99.0	78.0	86.0	90.0	95.0	97.0	93.0	88.0	69.0	55	47
24	Ve850	Vestas	-99.0	79.0	87.0	93.0	97.0	95.0	92.0	86.0	75.0	65	52
25	Ve1650	Vestas	-99.0	84.0	92.0	95.0	98.0	98.0	96.0	90.0	78.0	70	66
26	Ve2000	Vestas	-99.0	89.6	94.9	97.2	98.5	98.4	97.4	94.4	-99.0	78	80
27	Ve3000	Vestas	-99.0	92.5	94.5	97.5	100.5	101.5	101.5	100.5	-99.0	105	90
28	Wm750	Windmaster	-99.0	75.0	81.0	87.0	91.0	95.0	97.0	89.0	78.0	45	--
r1	250	--	63.1	71.0	80.1	89.7	89.6	92.3	90.7	83.3	72.0	51	--
r2	600	--	-99.0	76.2	86.2	92.3	93.0	89.8	88.0	87.4	89.3	40	--
r3	1300	--	-99.0	81.8	88.8	90.8	92.1	90.7	90.3	87.9	82.8	66	62
r4	600	--	73.8	83.0	88.5	93.0	96.9	95.0	89.3	83.9	72.9	65	44
r5	800	--	-99.0	81.7	90.4	94.7	96.7	96.1	94.5	90.4	77.5	--	--
r6	1800	--	71.0	82.0	92.0	94.0	98.0	98.0	93.0	88.0	4.9	--	--
r7	2000	--	-99.0	82.2	90.9	95.2	97.2	96.6	95.0	90.9	78.0	--	--

r8	2300	--	-99.0	86.3	95.2	99.4	99.2	94.6	89.9	85.7	82.2	85	71
r9	1500	--	-99.0	86.0	91.0	96.0	97.0	98.0	94.0	88.0	75.0	80	70
r10	80	--	-99.0	74.2	82.9	87.2	89.2	88.6	87.0	82.9	70.0	40	18
r11	250	--	-99.0	83.2	91.9	96.2	98.2	97.6	96.0	91.9	79.0	51	30
r12	750	--	-99.0	80.0	90.0	92.0	93.0	94.0	94.0	94.0	-99.0	--	--
r13	500	--	-99.0	72.0	92.0	93.0	98.0	99.0	89.0	85.0	75.0	39	40
r14	900	--	-99.0	78.0	89.0	94.0	96.0	94.0	92.0	91.0	83.0	70	52
r15	950	--	68.2	73.4	81.4	93.9	95.8	95.1	95.3	90.2	85.1	46	54
r16	2300	--	-99.0	82.0	95.0	95.0	95.0	96.0	97.0	95.0	89.0	100	90
r17	2500	--	-99.0	90.0	95.0	99.0	99.0	96.0	97.0	92.0	79.0	80	90
r18	500	--	-99.0	76.3	84.9	89.7	92.9	88.9	87.6	86.4	78.3	35	37
r19	100	--	-99.0	73.0	81.7	86.0	88.0	87.4	85.8	81.7	68.8	25	19
r20	2000	--	-99.0	84.2	92.9	97.2	99.2	98.6	97.0	92.9	80.0	80	82
r21	500	--	-99.0	79.0	87.0	89.0	91.0	89.0	88.0	81.0	66.0	40.5	39
r22	600	--	-99.0	78.6	86.5	88.8	92.6	94.0	91.6	88.4	74.0	55	44
r23	660	--	-99.0	78.0	86.0	90.0	95.0	97.0	93.0	88.0	69.0	55	47
r24	850	--	-99.0	79.0	87.0	93.0	97.0	95.0	92.0	86.0	75.0	65	52
r25	1650	--	-99.0	84.0	92.0	95.0	98.0	98.0	96.0	90.0	78.0	70	66
r26	2000	--	-99.0	89.6	94.9	97.2	98.5	98.4	97.4	94.4	-99.0	78	80
r27	3000	--	-99.0	92.5	94.5	97.5	100.5	101.5	101.5	100.5	-99.0	105	90
r28	750	--	-99,0	75,0	81,0	87,0	91,0	95,0	97,0	89,0	78,0	45	--

Appendix E: Sound power data sources

manufacturer	type	version	max. power kW	hub height m	diameter m	mode	source	reference nr	date
Bonus	Bonus MKIV	600/44-40	600				Danak		aug-96
Bonus	Bonus 1300	Bonus 1300	1300	66	62	13 rpm	Van Grinsen Advies	Kenmerk SWNN-Rommens.TS1.doc	dec-00
Bonus	Bonus 1300	Bonus 1300	1300	50	62	19 rpm	Delta Acoustics & Vibration	K 877166	07-03-2000
Bonus	Bonus 1300	Bonus 1300	1300	66	62	19 rpm	Van Grinsen Advies	Kenmerk SWNN-Rommens.TS1.doc	dec-00
Enercon	E-40	E-40/6.44	600	50	44		Lichtveld Buis & Partners BV	R068201aaA1.tk	mei-04
Enercon	E-40	E-40/6.44	600	50	44		Lichtveld Buis & Partners BV	R068201aaA0.tk	mei-04
Enercon	E-40	E-40/6.44	600	46	44		Enercon technische data	S-tab E-40-600-44 WT 04_2001	apr-01
Enercon	E-40	E-40/6.44	600	50	44		Enercon technische data	S-tab E-40-600-44 WT 04_2001	apr-01
Enercon	E-40	E-40/6.44	600	58	44		Enercon technische data	S-tab E-40-600-44 WT 04_2001	apr-01
Enercon	E-40	E-40/6.44	600	65	44		Windtest	WT 1809/01	jun-01
Enercon	E-40	E-40/6.44	600	75	44		Enercon technische data	S-tab E-40-600-44 WT 04_2001	apr-01
Enercon	E-40	E-40/6.44	600	78	44		Enercon technische data	S-tab E-40-600-44 WT 04_2001	apr-01
Enercon	E-66	E-66/20.70	2000				Hayes McKenzie Partnership	HM:1471/R1	feb-04
Enercon	E-70	E-70 E4	2000	58	71		Enercon	SA-04-SPL Guarantee E-70 2,0MW	feb-06
Enercon	E-70	E-70 E4	2000	64	71		Enercon	SA-04-SPL Guarantee E-70 2,0MW	feb-06
Enercon	E-70	E-70 E4	2000	85	71		Enercon	SA-04-SPL Guarantee E-70 2,0MW	feb-06
Enercon	E-70	E-70 E4	2000	98	71		Enercon	SA-04-SPL Guarantee E-70 2,0MW	feb-06
Enercon	E-70	E-70 E4	2000	113	71		Enercon	SA-04-SPL Guarantee E-70 2,0MW	feb-06
Enercon	E-70	E-70 E4	2000	85	71		WIND-consult GmbH	test report WICO 392SEA03/03	aug-04
Enercon	E-70	E-70 E4	2300	58	71		Enercon	SA-04-SPL Guarantee E-70 2,3MW	feb-06
Enercon	E-70	E-70 E4	2300	64	71		Enercon	SA-04-SPL Guarantee E-70 2,3MW	feb-06
Enercon	E-70	E-70 E4	2300	85	71		Enercon	SA-04-SPL Guarantee E-70 2,3MW	feb-06
Enercon	E-70	E-70 E4	2300	98	71		Enercon	SA-04-SPL Guarantee E-70 2,3MW	feb-06
Enercon	E-70	E-70 E4	2300	113	71		Enercon	SA-04-SPL Guarantee E-70 2,3MW	feb-06
Enercon	E-70	E-70 E4	2300	85	71	mode 2	WIND-consult GmbH	test report 049SE206/01	mrt-06
Enron	TW 1.5s	TW 1.5s	1500	80	70	11 rpm	Lichtveld Buis & Partners BV	R060388acA0.tk	sep-00
Enron	TW 1.5s	TW 1.5s	1500	80	70	22 rpm	Lichtveld Buis & Partners BV		sep-00

NedWind	NedWind 40	NedWind 40	500	39	40		Peutz & Associes BV	FA 2024-2	09-12-1992
NegMicon	NM52	NM52/900	900	70	52	15 rpm	Lichtveld Buis & Partners BV	R052 495abA1.tk	11-12-2000
NegMicon	NM52	NM52/900	900	70	52	22 rpm	Lichtveld Buis & Partners BV	R052 495abA1.tk	11-12-2000
NegMicon	NM52	NM52/900	900	40	52	22,4 rpm	NEG Micon Holland	NM-Heeres.TS1	jun-01
NegMicon	NM54	NM54/950	950	46	54	15 rpm	Van Grinsven Advies	Kenmerk WNW-Rodenthuis.TS7.doc	jul-03
NegMicon	NM54	NM54/950	950	46	54	22 rpm	Van Grinsven Advies	Kenmerk WNW-Rodenthuis.TS7.doc	jul-03
NegMicon	NM54	NM54/950	950	55	54	22 rpm	Windtest	WT2127/02	mrt-02
Nordex	N80	N80	2500	80	80		Gemeenten Nijkerk, Ermelo en Putten/Locatieonderzoek windpark A28	MD-WR2004.0233	11-05-2004
Nordex	N90	N90	2300	100	90	16.9 rpm	Lichtveld Buis & Partners BV	R052619aaA1.tk	24-10-2003
Nordtank	NTK37	NTK37/500	500	35	37		Nordtank	Ref.no. S.hla.931209d1	dec-93
Nordtank	NTK37	NTK37/500	500	42.5	37		Jansen Raadgevend Ingenieursbureau	Kenmerk 2309M01L.R06	13-05-1994
Nordtank	NTK37	NTK37/500	500	42.5	37		Lichtveld Buis & Partners BV	R52372A3.TK	12-09-1997
Nordtank	NTK43	NTK43/600	600	40	43		Schreuder Groep Ingenieurs/Adviseurs	BOA\9450\FK	02-12-1997
Repower	MM82	MM82	2000	80	82		Marshall Day Acoustics	Rapport nr. 03147C	05-11-2003
Repower	MM82	MM82	2000	80	82		Windtest Kaiser-Wilhelm-Koog GmbH	WT3236/04	29-03-2004
Vestas	V39	V39-500kW	500	41	39		Lichtveld Buis & Partners BV	R52 303A0.TK	01-07-1994
Vestas	V44	V44-600kW	600	41	44		Vestas Wind Systems A/S	Item no. 941688.R0	23-05-1996
Vestas	V44	V44-600kW	600	55	44		Lichtveld Buis & Partners BV	R52 451A1.tk & R52 451A2.tk	27-8-1997 & 20-7-1999
Vestas	V44	V44-600kW	60	41	72		Acoustica as	Item No.: 941687.R0	16-04-1996
Vestas	V47	V47-660 kW	660	55	47		Lichtveld Buis & Partners BV	R52 500A0.tk	23-12-1998
Vestas	V52	V52-850kW	850	65	52		Lichtveld Buis & Partners BV	R052347abA1.tk	24-07-2003
Vestas	V66	V66-1650kW	1650	70	66	15 rpm	Lichtveld Buis & Partners BV	R58 345A0.TK	01-12-1998
Vestas	V66	V66-1650kW	1650	70	66	19 rpm	Lichtveld Buis & Partners BV	R58 345A0.TK	01-12-1998
Vestas	V80	V80-2,0MW	2000	60	80		Lichtveld Buis & Partners BV	R068261aaA0.tk	26-07-2006
Vestas	V80	V80-2,0MW	2000	80	80		Hayes McKenzie Partnership	Report 1610-R1	
Vestas	V80	V80-2,0MW	2000	68	80	101dBA	Lichtveld Buis & Partners BV	R052619aaA1.tk	24-10-2003
Vestas	V80	V80-2,0MW	2000	68	80	102dBA	Lichtveld Buis & Partners BV	R052619aaA1.tk	24-10-2003
Vestas	V80	V80-2,0MW	2000	68	80	103dBA	Lichtveld Buis & Partners BV	R052619aaA1.tk	24-10-2003
Vestas	V80	V80-2,0MW	2000	68	80	104dBA	Lichtveld Buis & Partners BV	R052619aaA1.tk	24-10-2003
Vestas	V80	V80-2,0MW	2000	68	80	105dBA	Lichtveld Buis & Partners BV	R052619aaA1.tk	24-10-2003
Vestas	V80	V80-2,0MW	2000	78	80	101dBA	Vestas R&D department	Item no.: 944406.12	15-01-2004
Vestas	V80	V80-2,0MW	2000	78	80	102dBA	Vestas R&D department	Item no.: 944406.12	15-01-2004
Vestas	V80	V80-2,0MW	2000	78	80	102.5dB	Vestas R&D department	Item no.: 944406.12	15-01-2004

Vestas	V80	V80-2,0MW	2000	78	80	104dBA	Vestas R&D department	Item no.: 944406.12	15-01-2004
Vestas	V80	V80-2,0MW	2000	78	80	105.1dBA	Vestas R&D department	Item no.: 944406.12	15-01-2004
Vestas	V80	V80-2,0MW	2000	100	80	101dBA	Vestas R&D department	Item no.: 944406.12	15-01-2004
Vestas	V80	V80-2,0MW	2000	100	80	102dBA	Vestas R&D department	Item no.: 944406.12	15-01-2004
Vestas	V80	V80-2,0MW	2000	100	80	102.5dBA	Vestas R&D department	Item no.: 944406.12	15-01-2004
Vestas	V80	V80-2,0MW	2000	100	80	104dBA	Vestas R&D department	Item no.: 944406.12	15-01-2004
Vestas	V80	V80-2,0MW	2000	100	80	105.1dBA	Vestas R&D department	Item no.: 944406.12	15-01-2004
Vestas	V90	V90-3.0MW	3000	65	90	mode 0	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	80	90	mode 0	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	90	90	mode 0	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	105	90	mode 0	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	65	90	mode 1	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	80	90	mode 1	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	90	90	mode 1	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	105	90	mode 1	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	65	90	mode 2	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	80	90	mode 2	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	90	90	mode 2	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	105	90	mode 2	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	65	90	mode 3	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	80	90	mode 3	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	90	90	mode 3	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	105	90	mode 3	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	65	90	mode 4	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	80	90	mode 4	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	90	90	mode 4	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	105	90	mode 4	Vestas Wind Systems A/S	Item no. 950011.R7	25-01-2005
Vestas	V90	V90-3.0MW	3000	85	90		Van Grinsen Advies	Kenmerk GR-Doelwijk.TS1.doc	jun-05
Vestas	V90	V90-3.0MW	3000	85	90		Van Grinsen Advies	Kenmerk GR-Doelwijk.TS1.doc	jun-05
Vestas	V90	V90-3.0MW	3000	105	90		Van der Boom Advies	opdrachtnummer 05-269	20-12-2005

Appendix F:

Transformation of response to wind turbine sound

In order to allow comparisons between studies, Miedema and Vos have suggested standardized transformations of proportion of annoyed measured at different scales, based on previous meta-analyses of Schultz[1]. The base is a scale from 0 (no annoyance at all) to 100 (very annoyed). The cut-off point for %A (proportion of respondents annoyed) is 50 and for %HA (proportion of respondents highly annoyed) is 72.

Response to wind turbine sound was in the study WINDFARMperception measured on a 5-point scale, starting with "do not notice" and with point 2 worded "notice, but not annoyed". The scale should start with "no annoyance at all" according to Miedema and Voss. Scale point 1 and 2 were therefore merged so that the scale became a 4-point scale from "not annoyed" to "very annoyed". The boundaries for the new 4- point scale were 0 – 25 – 50 – 75 – 100. For transformation to %A and %HA the following procedure was carried out in accordance with Miedema and Voss:

%A:
- Scale points 1, 2 and 3 were set to 0.00 (not annoyed)
- Scale points 4 and 5 were set to 1.00 (annoyed)

%HA:
- Scale points 1, 2 and 3 were set to 0.00 (not annoyed)
- Scale point 4 was set to (75 – 72)/(75 – 50) = 0.12
- Scale point 5 was set to 1.00 (highly annoyed)

The mean values of the variables %A and %HA for each category of exposure are presented below. The mean values correspond to the prevalence of annoyed and highly annoyed, respectively. In this case, the 95% confidence intervals are calculated in SPSS, i.e. 1.96 x SE (standard error of the mean). This could be questioned, but it simplifies the procedure and it is the common way to calculate the confidence interval of a mean value.

The proportions of respondents annoyed or highly annoyed by wind turbine noise outdoors are presented in table F.1. The proportions of respondents annoyed increased with increasing sound levels up to 40 – 45 dBA, and then decreased.

Table F.1: %A and %HA by wind turbine noise outdoors

	Sound pressure levels, dBA				
	<30	30-35	35-40	40-45	>45
n = 708	178	213	159	93	65
%A	2	8	18	18	12
%HA	1	2	7	13	7

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[1] H,M.E.Miedema, H.Voss, Exposure-response relationships for transportation noise. Journal of the Acoustical Society of America, 104 (1998), 3432 - 3445.

The proportions of respondents annoyed and highly annoyed are plotted in figure F.1.

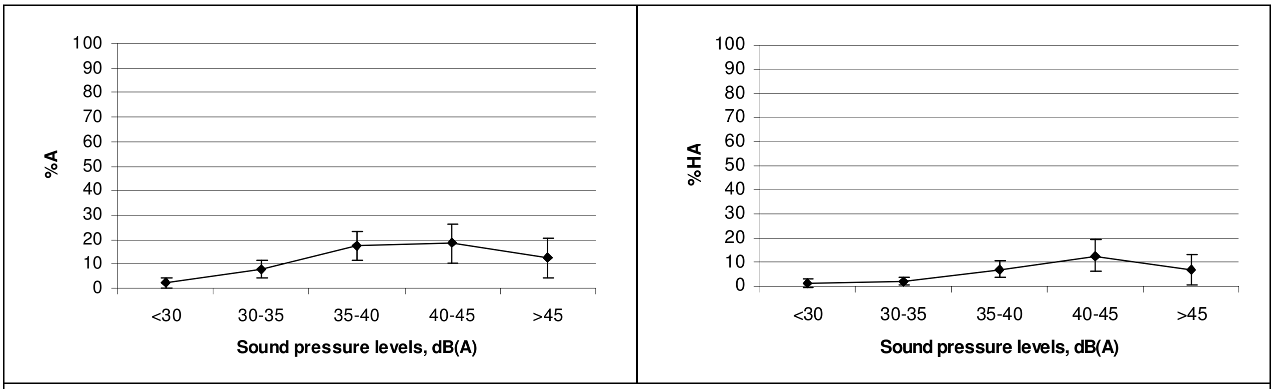


Figure F.1: response to wind turbine sound outdoors: left: %A, right %HA, with 95% CI.

The number of respondents that benefited economically from wind turbines was higher at higher sound levels than at lower. The proportions of respondents that were annoyed or highly annoyed by wind turbine sound were larger when the respondents who benefited from wind turbines were excluded in comparison to all respondents (table F.2).
In table F.2 also the average sound level in each sound level interval is given. This is the logarithmic average of the calculated sound pressure levels of all respondents in that interval.

Table F.2: %A and %HA by wind turbine sound outdoors; only respondents that did not benefit economically from wind turbines

	Sound pressure levels, dBA				
sound level interval	<30	30-35	35-40	40-45	>45
average sound level	28.1	32.7	37.4	42.7	49.0
n = 586	166	199	140	60	21
%A	2	8	20	25	29
%HA	1	2	8	19	16

The proportions of respondents annoyed or highly annoyed by wind turbine sound, but not benefiting economically from the wind turbines, are also shown in figure F.2. The confidence intervals were large, especially at the higher sound levels, due to a low number of respondents not benefiting economically in these group.

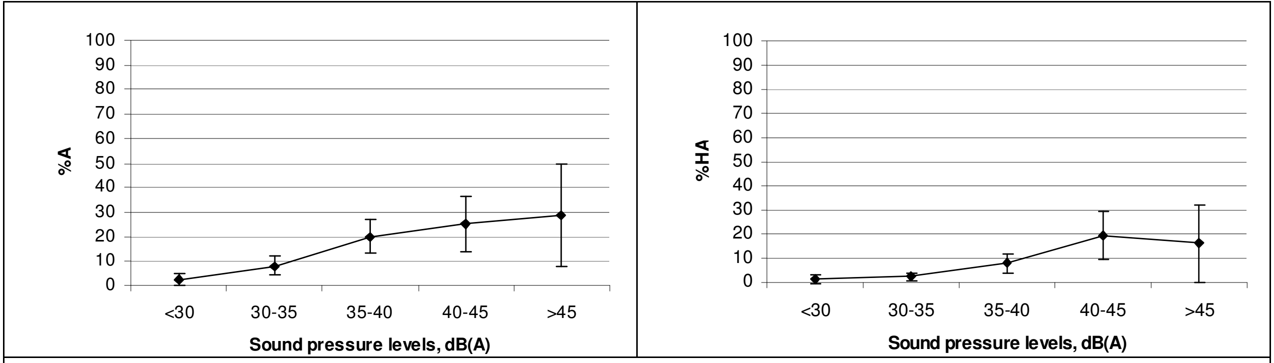


Figure F.2: response to wind turbine sound outdoors: (i) %A, (ii) %HA, with 95% CI; only respondents who did not benefit economically from wind turbines.

Appendix G: Comparison with previous Swedish studies

The present study shows similar results as two previous studies in Sweden. One Swedish study ("study A") was carried out in 2000 in a flat landscape that was mainly agricultural but also comprised built-up areas (n = 341). The second study ("study B") was carried out in 2005 in complex terrain (hilly or rocky) as well as in flat landscape, including both rural areas and built-up areas (n = 754). The levels of sound from wind turbines outside the dwelling of the respondents were calculated with a slightly different model than in the present study, but it is of interest to compare the proportion of respondents that noticed sound at different sound levels despite the differences in calculations. Almost no respondents in the Swedish study benefited economically from wind turbines. The Swedish respondents are therefore compared with the Dutch respondents that did not benefit economically from wind turbines.

The proportion of respondents that could hear sound from wind turbines outside their dwelling in the Dutch study were about the same as in the Swedish study A, carried out in a flat landscape (figure G.1).

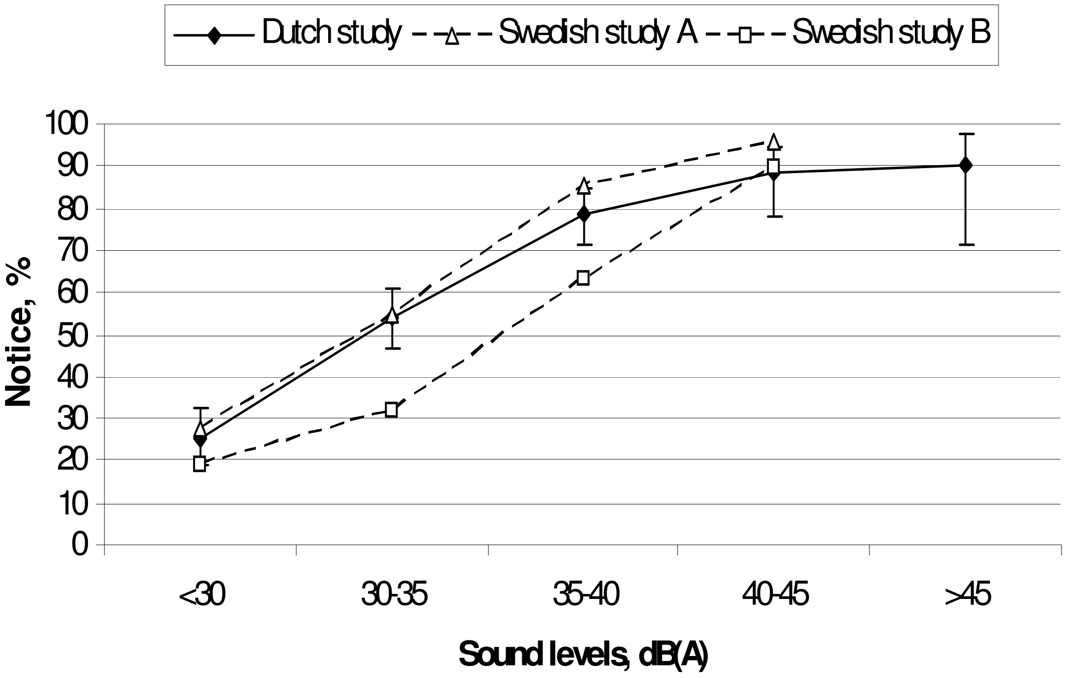


Figure G.1: perception of wind turbine sound; comparisons between the Dutch study (only respondents that did not benefit economically) and the Swedish studies A and B (with 95% CI for the Dutch study).

The proportion of respondents that were rather or very annoyed by sound from wind turbines were approximately the same in the Dutch study and in the Swedish study A up to 35 – 40 dBA. The Dutch study showed a lower proportion of annoyed persons at 40 – 45 dBA than the Swedish study A (flat terrain), but a higher than the Swedish study B (mixed terrain).

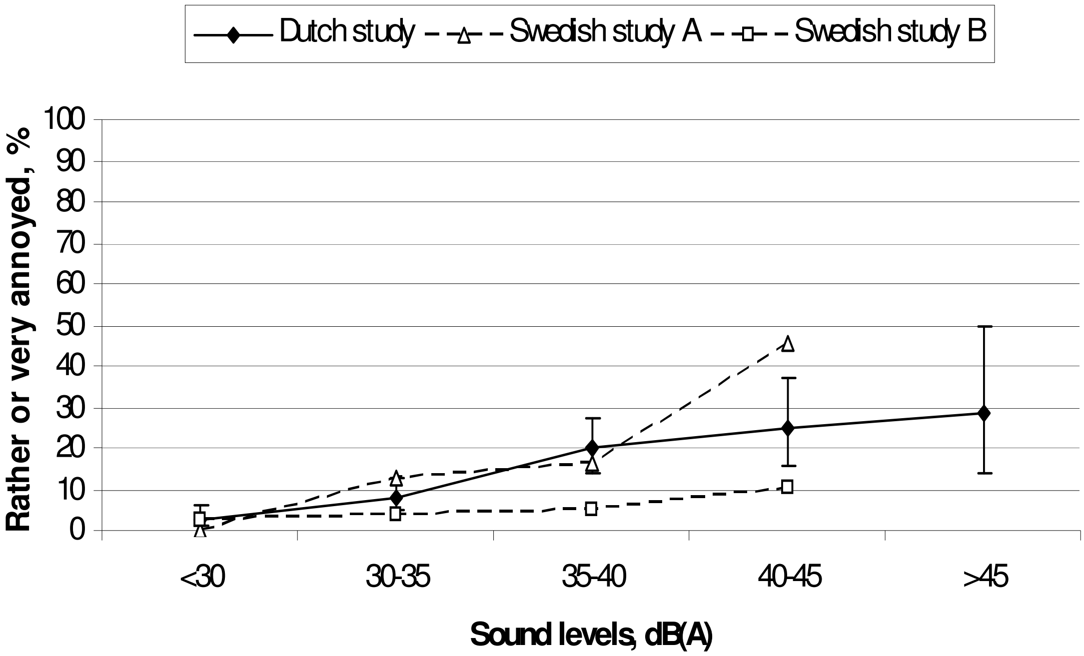


Figure G.2. Annoyance with wind turbine sound; comparisons between the Dutch study (only respondents that did not benefit economically) and the Swedish studies A and B (with 95% CI for the Dutch study).

Appendix H: Annoyance from road traffic noise

For transformation of the results in this study to the standardized proportion of annoyance proposed by Miedema and Vos see Appendix F. Annoyance from road traffic was measured in two questions in the questionnaire: questions 10-6 and 10-8

Below the mean values of the variables %A and %HA are presented for each category of exposure. The mean values correspond to the prevalence of annoyed and highly annoyed, respectively. In this case, the 95% confidence intervals are calculated in SPSS, i.e. 1.96 x SE (standard error of the mean). This could be questioned, but it simplifies the procedure and it is the common way to calculate the confidence interval of a mean value.

The proportions of annoyed and highly annoyed by road traffic noise were compared with Lden-values of road traffic (Table H.1). The proportions increased with increasing immission levels. Also for annoyance with road traffic noise, the two measurements showed similar result, indicating good internal consistency of the questionnaire.

Miedema and Oudshoorn have presented third grade polynomials for annoyance with road traffic noise based on 18 previous studies [Miedema and Oudshoorn 2001]. Their polynomials do not comprise an intercept. Instead, the Lden-values are subtracted by 37 and 42 respectively to force the curve towards null. Their proposed polynomials are

$$\%A = 0.0001795 \cdot (Lden-37)^3 + 0.021 \cdot (Lden-37)^2 + 0.535 \cdot (Lden-37)$$

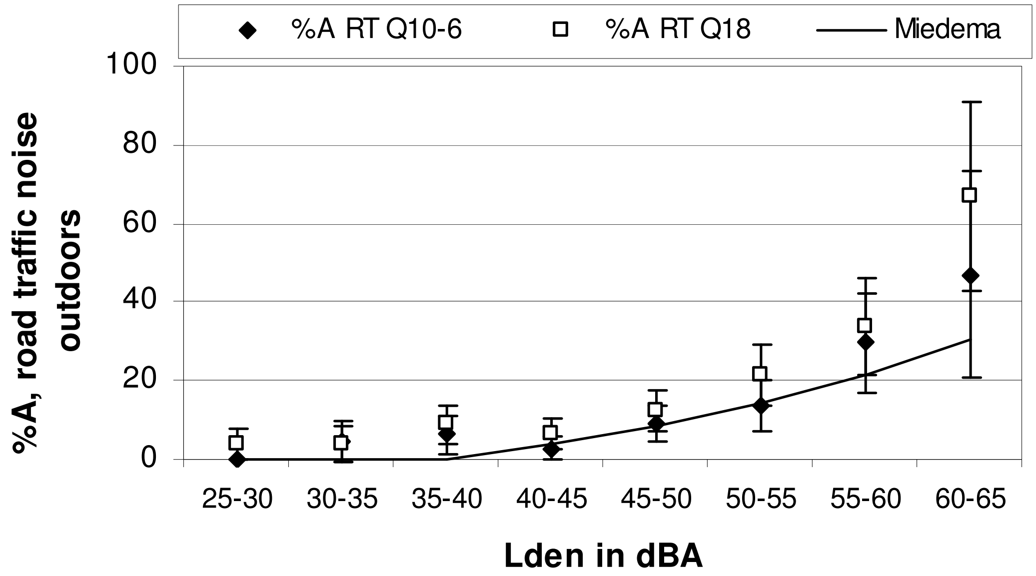
$$\%HA = 0.000987 \cdot (Lden-42)^3 - 0.014 \cdot (Lden-42)^2 + 0.512 \cdot (Lden-42)$$

The proportion of annoyed persons by road traffic noise according to these formulae is also shown in tabel H.1.

Table H.1: %A and %HA by road traffic noise outdoors in 5-dB Lden intervals

Lden: 5-dB intervals	<30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70
Question 10-6									
n = 715	82	66	96	143	145	111	54	17	1
%A	0	5	6	3	9	14	30	47	0
%HA	0	3	2	0	1	2	12	37	
Question 18									
n = 700	78	64	96	139	142	107	55	18	1
%A	4	4	9	6	12	21	34	67	
%HA	0	0	1	1	5	10	14	41	
Miedema curve									
Lden: midpoint of interval		32.5	37.5	42.5	47.5	52.5	57.5	62.5	
%A		0	0	4	8	14	21	30	
%HA		0	0	0	3	8	15	25	

In figure H.1 the percentages of (severe) annoyance are compared with the standardized curves of Miedema *et* al. It shows that the standard curves match the the 95% confidence intervals of the percentages in this study, except for %A values at 35-40 and 60-65 dBA.



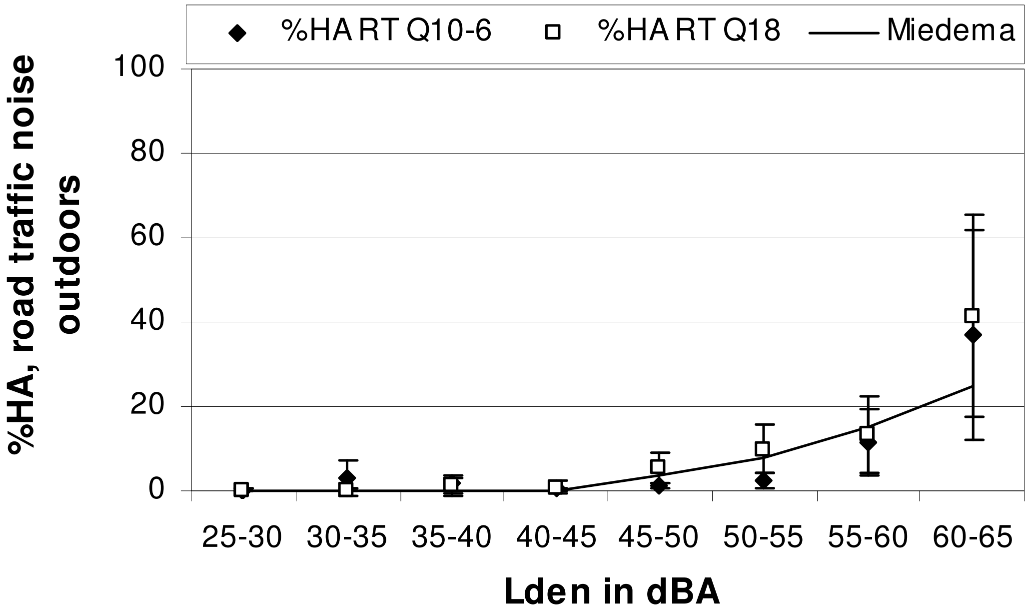


Figure H.1: comparison of percentage annoyed (above) and highly annoyed (below) with raod traffic, with 95% confidence intervals, with standardized percentages fiom Miedema et al*; based on response from questions 10-6 and 18 in questionnaire used in this study.*

Appendix I:
Remarks in the questionnaires added by respondents

Most questions in the questionnaire required ticking one of the answering possibilities. To some questions respondents could add a remark. Although the remarks were varied, they could be classified in a small number of categories that seemed appropriate for each question.

Changes in the living environment
Before any specific questions on wind turbines were presented, two questions were posed about changes for the better or worse in the living environment during the last years. To question 7 respondents could add remarks on positive changes, to question 8 on negative changes.
There were 157 remarks on positive changes. These have been categorized as follows in order of prevalence:

- 73 on improvements in the area (walking, cycling, green spaces, playing areas, meeting places, shops, better housing, schools);
- 36 on personal changes;
- 34 on infrastructure (sewage, roads), public transport and (slower/less) trafffic;
- 14 on industrial and economical improvements (wind turbines included) and other issues (5).

There were 254 remarks on negative changes. These have been categorized similarly:

- 87 on wind turbines
- 79 on deteriorations in the area (youth, recreation, busier, having to move because of new planning);
- 71 on busier infrastructure and less agriculture;
- 17 on personal changes.

In all, changes in the area were most often mentioned, the positive ones balancing the negative ones in numbers. Infrastructure was the next topic, with twice more negative than positive remarks. Wind turbines were most frequently mentioned in a negative way. Personal changes were least often mentioned, but mostly in a positive way.

Impact of busy roads and wind turbines
To question 13, the first question in the road traffic section, respondents could add a remark on the positive or negative impact of busy roads on the landscape scenery. The 101 remarks can be categorized as:

- 22 were positive (nice trees, no problems/disturbance, easy for a car, lively);
- 29 were neutral (economical necessity, part of society) or (19) not clear about the impact;
- 50 were negative (heavy/fast traffic, spoils the landscape/tranquillity, fragments the countryside, restless).

To question 21, the first question in the wind turbine section, respondents could add a remark on the positive or negative impact of wind turbines on the landscape scenery. The 209 remarks can be categorized as follows:

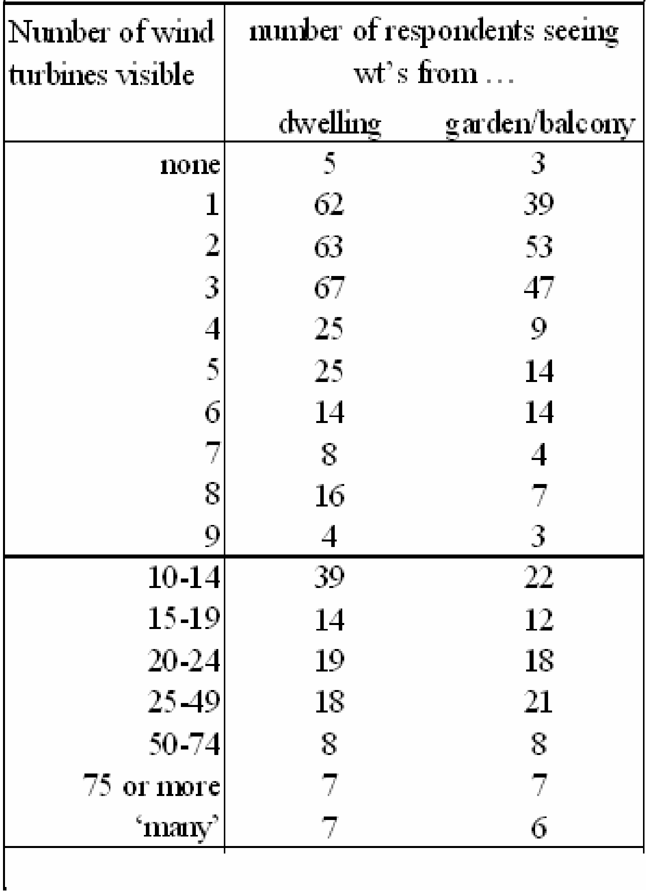
- 110 were negative on the visual impact (of which 8 specifically mentioned the shadows), mostly because of the inappropriateness in the landscape and the restlessness caused by the movement;
- 27 were positive on the visual impact, mostly because it added a dynamic character or made wind direction and speed readily visible;
- 37 commented on the environmentally friendly character or (7) economical benefits of wind energy, two of these were negative (low yield);
- 16 concerned not visual, but (negative) noise impact.

To question 25 respondents could add a personal characterization of wind turbine sound, other than the eight possibilities given. 26 remarks were given, of which:

- 7 gave a description (liking the sound to an agricultural machine, many frogs, a washing machine, lightly clapping, ticking);
- 7 were clearly positive about it (like music, pleasant, makes one sleep nicely, rhythmic, restful);
- 5 mentioned the changing character of the sound.

Number of visible wind turbines
In question 33 respondents were asked whether they could see one or more turbines from their dwelling or from their garden/balcony. 401 respondents gave a number for the indoor view, 287 for the outdoor view. The numbers are summarized in table I.1. Remarkably, respondents see a lower number outdoors compared to from within the dwelling, the more so when there are less than 15 wind turbines. Perhaps this is because they usually have a garden or balcony on one side of the house, but windows at several sides; or perhaps they have a better view from upstair windows.

Table I.1: number of wind turbines visible from respondents' dwellings or garden/balcony (as reported by resp. 401 and 287 respondents)



Number of wind turbines visible	number of respondents seeing wt's from …	
	dwelling	garden/balcony
none	5	3
1	62	39
2	63	53
3	67	47
4	25	9
5	25	14
6	14	14
7	8	4
8	16	7
9	4	3
10-14	39	22
15-19	14	12
20-24	19	18
25-49	18	21
50-74	8	8
75 or more	7	7
'many'	7	6

Sounds disturbing sleep and final remarks
In question 42 respondents were asked by which sound(s) their sleep was disturbed. 244 respondents mentioned one or more sources. These can be categorized as follows, in order of prevalence:

- road traffic (in 93 cases of which 17 mopeds/scooters/motorcycles);

- outdoor music, parties and people, in many cases youth, (42)
- wind turbines (35);
- animals, mostly dogs and cows (26);
- indoor sources, mostly children and –snoring- partner (22);
- neighbours (17);
- agricultural activities (15);
- airplanes (13).

Finally, respondents could add a remark that they thought might be of interest for this study and not sufficiently addressed in this questionnaire. 178 respondents added a remark here, ranging from very personal to more general observations of their living environment. With respect to the topic of this study, 31 remarks referred to wind turbines (of which 9 positively, 22 negatively), 15 to other noise sources and 5 to other supposedly environmental hazards (radiation, waste).