National Institute for Public Health
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Health implication of road, railway and aircraft noise in the European Union

Provisional results based on the 2nd round of noise mapping

RIVM Report 2014-0130

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Colophon

D.J.M. Houthuijs
A.J. van Beek
W.J.R. Swart
E.E.M.M. van Kempen

Contact:
Danny Houthuijs
Centre for Sustainability, Environment and Health
danny.houthuijs@rivm.nl

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Abstract

This report describes, on request of the European Commission, the health and well-being implications of road traffic, railway and aircraft noise in Europe. The emphasis is on the description of the methods for health impact assessment of environmental noise. Exposure data for 2012 is available only for a selection of agglomerations, major roads, major railways and major airports and includes only levels above 55 dB L_{den} and 50 dB $L_{night.}$ The methods can be used in a later stage to assess the full impact in the European Union when complete information about the noise exposure distribution for these sources becomes available.

At least about 19.8 million adults in Europe are annoyed by noise from road traffic, railways, aircrafts or industry; 9.1 million of them are highly annoyed. It is estimated that 7.9 million adults have sleep disturbance due to night time noise; 3.7 million of them are severely sleep disturbed.
The exposure contributes to about 910 thousand additional prevalent cases of hypertension and to 43 thousand hospital admissions per year and about 10 thousand premature deaths per year related to coronary heart disease and stroke. About 90% of the disease burden is related to road traffic noise.

These results for 33 European countries (EU28 plus Iceland, Liechtenstein, Norway, Switzerland and Turkey) should be considered provisionally, since they are based on the available data (database of August 2013). In this database the completeness for road traffic noise - the most dominant source - is 36% for major roads and 62% for major agglomerations.

Keywords: noise, health, annoyance, sleep disturbance, Europe

Publiekssamenvatting

[Gezondheidseffecten voor omwonenden van geluid van weg-, vlieg en treinverkeer in Europa]

Ten minste 19,8 miljoen volwassenen die in Europa in een stedelijk gebied of in de buurt van grote snelwegen, grote vliegvelden of hoofdspoorlijnen wonen zijn gehinderd door het geluid dat hiervan afkomstig is. Van hen zijn 9,1 miljoen mensen ernstig gehinderd. Zij hebben last van gevoelens van irritatie, boosheid en onbehagen. Nachtelijk geluid kan de slaap verstoren, bijvoorbeeld door niet te kunnen inslapen of tussentijds wakker te worden. Naar schatting hebben 7,9 miljoen mensen hier last van en 3,7 miljoen van hen ervaart dit als ernstig. Daarnaast draagt omgevingslawaai bij een hogere bloeddruk, hart- en vaatziekten, beroerte en vroegtijdig overlijden. De voornaamste bron van hinder is lawaai van wegverkeer.
De blootstelling aan omgevingslawaai in Europa leidt tot ongeveer 910 duizend gevallen van verhoogde bloeddruk en 43 duizend ziekenhuisopnames per jaar door hart- en vaatziekten en beroertes; het aantal vroegtijdige sterfgevallen per jaar als gevolg van de blootstelling is naar schatting circa 10 duizend per jaar. Ongeveer 90 procent van deze ziektelast is gerelateerd aan wegverkeerslawaai. Dit zijn de voorlopige resultaten voor 33 Europese landen (28 lidstaten van de Europese Unie plus IJsland, Liechtenstein, Noorwegen, Zwitserland en Turkije), die als een onderschatting worden bestempeld. Nog niet alle informatie van de landen over het peiljaar 2011 is beschikbaar. Het RIVM beschrijft, op verzoek van de Europese Commissie, de gevolgen voor de gezondheid en het welbevinden van geluid afkomstig van wegverkeer, spoorwegen en vliegverkeer in Europa.
Er is sprake van een onderschatting omdat de blootstellinggegevens alleen beschikbaar zijn voor een selectie van de agglomeraties, snelwegen, spoorwegen en luchthavens. Verder rapporteren de landen alleen het aantal mensen dat woont bij hoge geluidniveaus (meer dan 55 dB voor het etmaal of 50 dB voor de nacht). Onder deze geluidniveaus kunnen ook effecten optreden, maar daarvan is de omvang niet bekend.

Trefwoorden: geluid, gezondheid, hinder, slaapverstoring, Europa

Contents

Summary

For the implementation of the Environmental Noise Directive (Directive 2002/49/EC), the European Commission, Directorate-General Environment, Directorate F – Strategy, Env.F.3. Knowledge, Risks and Urban Environment requested the National Institute for Public Health and the Environment, the Netherlands, technical support in the form of a description of the health and well-being implications of road traffic, railway and aircraft noise in the European Union.

Since the second round of noise mapping is far from complete yet, this report focusses on the description of the methodology for health impact assessment of environmental noise. The provided results of the health impact assessment should be considered as provisional, since they are based on available data (database of August 2013). In this database the completeness for road traffic noise - the most dominant source - is 36% for major roads and 62% for major agglomerations.

The health implications of environmental noise can be described as the number of adults with (severe) annoyance and (severe) sleep disturbance, the number of children with reading impairment that can be attributed to noise exposure, and the number of residents with hypertension, hospital admissions due to cardiovascular disease and premature mortality related to noise exposure. These health effects are the most investigated non-auditory health endpoints of noise exposure.

For the EEA33, it is estimated that at least 19.8 million adults are annoyed due to noise from road traffic, railways, aircrafts or industry; 9.1 million of them are highly annoyed. 7.9 Million adults are expected to have noise related sleep disturbance; 3.7 million of them are severely sleep disturbed.

The exposure to environmental noise contributed to almost 900 thousand additional prevalent cases of hypertension in 2012, to 43 thousand additional cases each year of hospital admissions and to 10 thousand cases of premature mortality each year due to coronary heart disease and stroke.

Almost 90% of the health impact is related to road traffic noise exposure. Nevertheless, the results may reflect only 20-35% of the total health impact of road traffic noise given the incompleteness of the second round of noise mapping and the limitations of the mapping to major agglomerations and major roads, and to levels above 55 dB L_{den} and levels above 50 dB L_{night}. The magnitude of the underestimation is unknown for railway, aircraft and industrial noise.

The reported numbers encompass uncertainties. The major sources of uncertainties are in the exposure response relations, the transferability of the relations to individual countries and the comparability of data on disease between countries.

Some potential points of improvement for the noise assessment in the framework of the END that might be considered for application in future noise assessments are identified in the report. In addition, it is recommended to investigate if it is possible to assess the full distribution of L_{den} and L_{night} among the population of the European Union by making use of a combination of data collected in the framework of the END and estimations for missing areas and for missing information on noise levels below 55 dB L_{den} and below 50 dB L_{night}.

1 Introduction

For the implementation of the Environmental Noise Directive (Directive 2002/49/EC), the European Commission, Directorate-General Environment, Directorate F – Strategy, Env.F.3. Knowledge, Risks and Urban Environment requested the National Institute for Public Health and the Environment technical support in the form of a description of the health and well-being implications of road, railway and aircraft noise in the European Union.

In a recent review the (non-auditory) effects of environmental noise exposure on public health were summarised (Basner et al., 2014). Noise exposure from transport sources and industry can lead to annoyance, sleep disturbance and related daytime sleepiness and increases the risk on hypertension and cardiovascular disease, and negatively affects cognitive performance in schoolchildren. Hypertension and cardiovascular disease are important risk factors for premature mortality, so the noise exposure can indirectly reduce life expectancy as well. For most of these health effects so-called exposure-response relations are available or can be derived from risk estimates reported in meta-analyses. Exposure-response relations describe the change in frequency of the health and well-being effects as function of the noise exposure. In this report, we make use of the available distributions for road traffic, railway, aircraft and industry noise of the second round of noise mapping (version August 2013) in combination with selected exposure-response relations to estimate the impact on various health and wellbeing endpoints for residents living above levels of 55 dB L_{den} and for levels above 50 dB L_{night}.

The emphasis in this report is the description of the methods for the health impact assessment since the noise exposure data is available only for a selection of agglomerations, major roads, major railways and major airports and includes only levels above 55 dB L_{den} and 50 dB L_{night}. The methods can be used in a later stage to assess the full impact in the European Union when complete information about the noise exposure distribution for these sources becomes available.

In chapter 2 we briefly describe the methods that were applied. Details of the methods can be found in the annexes. In chapter 3 the results of the health impact assessment are given. The discussion and conclusions can be found in chapter 4 and 5.

2 Methods

2.1 Introduction

Figure 1 summarises the methodology used in this report and illustrates the type of input data necessary to estimate the number of people affected by noise exposure.

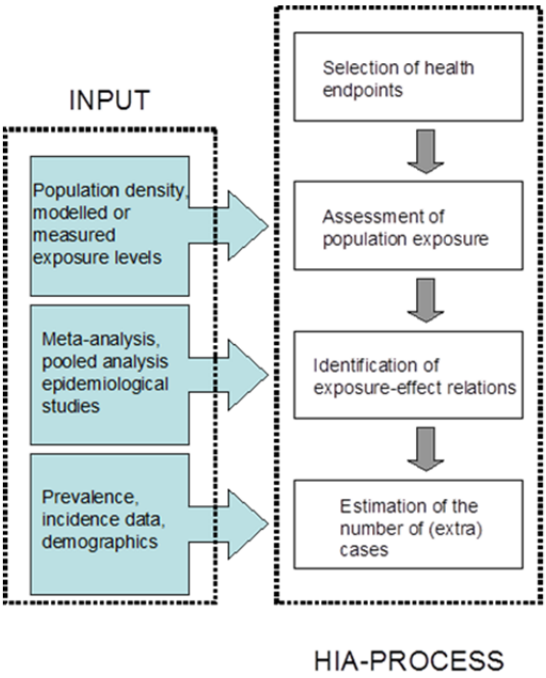

Figure 1. Overview of the methodology and input data used for the estimation of the number of people affected by noise exposure

In the Introduction we summed up the various health and well-being endpoints that were identified as the most relevant for environmental noise exposure and for which exposure-response relations are available. In this chapter we describe for each of the endpoints the origin of the exposure-response relations that we applied and the way we used them in the health impact assessment, if necessary making use of information on demographics and prevalence/incidence of disease data. For details of the implementation for the specific endpoint, we refer to the annexes.

2.2 Annoyance

Annoyance is one of the most widespread and well-documented responses to noise. It is a collective term for several negative reactions such as irritation, dissatisfaction or anger, which appear when noise disturbs someone’s daily activities. Exposure-response relations for noise annoyance among adults have been widely studied, and large datasets have allowed the construction of ‘generalised’ relations. At the moment several source-specific exposure-response relations for annoyance are available.
In 2000, Miedema and Oudshoorn prepared a report on relations between noise from road traffic, railways and aircrafts and annoyance (Miedema and Oudshoorn, 2000). The European Commission Working Group on Dose/Effect adopted these ‘generalised’ relations for L_{den} in 2002 (Working group, 2002).

The relations are based on a pooled analysis of a large number of international studies that were carried out between 1972 and 1993. The exposure-response relations were expressed as simple polynomials as well as in the form of more precise equations. For the polynomials the percentage highly annoyed was forced through zero at 42 dB L_{den} mistakenly indicating that no severe annoyance can take place below 42 dB L_{den}. For the health impact assessment we used the more precise relations (Miedema and Oudshoorn, 2001); for the estimation of the probability of (severe) annoyance above 55 dB L_{den} the more precise relations and the polynomials are in good agreement with each other.

Several authors suggested that the relation for aircraft noise has become steeper over time, and that the adopted relation was 'outdated' (Guski, 2004; Van Kamp and Van Kempen, 2005; Babisch et al., 2009; Janssen et al., 2011). Janssen and Vos (2009) analysed 7 European aircraft noise studies that were carried out after 1995 and derived an exposure-response relation between L_{den} and annoyance. In 2010, the European Environment Agency recommended to use the updated exposure-response relation with the post-1990 data (EEA, 2010); this relation was applied in this report.

The number of studies on annoyance from industry noise is scarce, so there is no exposure-response relation available based on pooled data. We used a relation for stationary sources based on a study in the Netherlands including 8 industrial sites (Miedema and Vos, 2004a).

To illustrate the used exposure-response relations, we show in Figure 2 the source-specific relations between L_{den} and severe annoyance.

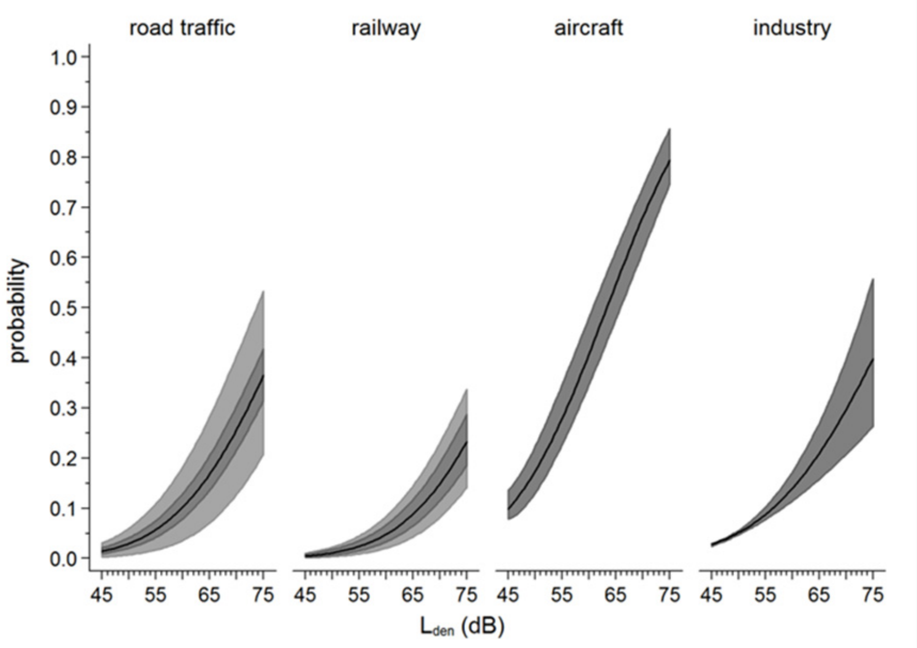

Figure 2. Source-specific exposure-response relations between L_{den} and severe annoyance with 95% confidence and 95% tolerance interval (source: Miedema and Oudshoorn, 2001; Miedema and Vos, 2004a; Janssen and Vos, 2009)

For Figure 2, we also calculated the 95% confidence interval (CI) and the – larger - 95% tolerance interval (only for road traffic and railway noise[1]) according to Oudshoorn and Miedema (2006). The 95% confidence interval specifies the accuracy of the mean of the relation. The 95% tolerance interval indicates the expected range in which a relation will be found when a new study will be executed. The tolerance interval gives an impression of the 'improvement' that is possible in a health impact assessment when a local derived exposure-response relation is used instead of a 'generalised' relation.

Social surveys into annoyance are carried out among adults; there is hardly any quantitative data on annoyance among children. For this reason, we calculated the annoyance and severe annoyance only for adults, using country level information from Eurostat about the fraction of adults (age 18 and older) in the total population for the year 2012. Details of the calculation of the number of (severely) annoyed adults can be found in annex 1.

2.3 Sleep disturbance

Since this report focusses on the long-term effects of noise exposure, the effects on sleep were limited to self-reported sleep disturbance. Although there is sufficient evidence for effects such as EEG-reactions, body movements, and reported awakenings in relation to L_{night}, these effects on sleep were not included in our assessment since these short-term reactions are usually considered as intermediate responses. In 2003 Miedema, Passchier-Vermeer and Vos published a report on night-time transportation noise and sleep disturbance (Miedema, Passchier-Vermeer and Vos, 2003); a separate report on self-reported sleep disturbance and aircraft noise followed one year later (Miedema and Vos, 2004b). The European Commission Working Group on Health and Socio-Economic Aspects subsequently prepared a position paper on dose-effect relations for night time noise in 2004 (Working group, 2004). Again simplified polynomial equations were given for the relation between L_{night} and the proportion (highly) sleep disturbed. More precise and updated equations for road traffic and railways were published in 2007 (Miedema and Vos, 2007) which were used for this report. Janssen and Vos (2009) updated the exposure-response relation for aircraft noise and sleep disturbance on the basis of 4 European aircraft noise studies that were carried out after 1995. We used this updated relation for this report.

No exposure-response relation is available for noise from industry. Since the exposure-response relations for (severe) annoyance are similar for noise from road traffic and noise from industry (see Figure 2), we used the relation between night-time road traffic noise (L_{night}) and self-reported sleep disturbance as an indication for the relation between night-time industry noise (L_{night}) and self-reported sleep disturbance.

Similar to annoyance, we calculated the number of sleep disturbed and severely sleep disturbed only for the adult population. Annex 2 describes the details of the calculation method.

[1] Since the relation for industry noise is based on one study, a tolerance interval cannot be calculated; for aircraft noise, we lack information to calculate the tolerance interval.

2.4 Reading impairment in school children

Several studies indicate that environmental noise can impair cognitive performance in school children. The cognitive tasks that can be influenced are central processing and language, such as reading comprehension, memory and attention. The World Health Organization (WHO, 2011) provides an exposure-effect graph to estimate the percentage of impairment and a hypothetical exposure-risk curve to estimate the percentage of the affected population. These relations are difficult to implement since the relations are not described in a quantitate manner. As alternative, data on reading comprehension from the European multi-centre RANCH study were re-analysed. The results on reading comprehension were earlier reported as exposure-effect relation: a 5 dB increase in aircraft noise exposure leads to an average delay in reaching the required reading ability of 1 to 2 months (Stansfeld et al., 2005 and Clark et al. 2006). In health impact assessments it is common to use exposure-response relations instead of exposure-effect relations. 'Reading impairment' was defined as the lowest 10 percentile of the reading scores of the children exposed to noise levels under 50 dB L_{den}. As next step, the relation between aircraft noise exposure and the probability on reading impairment was assessed for exposure levels above 50 dB. This resulted in an odds ratio of 1.38 (95%CI: 1.09-1.75) per 10 dB change in aircraft noise level (adopted from Van Kempen, 2008).

From the approach it follows that, otherwise than for noise related annoyance and sleep disturbance, there is a certain percentage of reading impairment in the absence of noise. The increased risk in reading impairment due to noise exposure can be described with a logistic model. In this non-linear model, the increased risk depends on the odds ratio, on the level of the noise exposure and on the 'base-line' prevalence (prevalence in the absence of noise: in this case 10%, the lowest 10 percentile). The exposure-response relation is given in Figure 3.

We calculated the additional cases of reading impairment for children in their school age (7 to 17 year old) only in relation to aircraft noise exposure. Details of the method can be found in Annex 3.

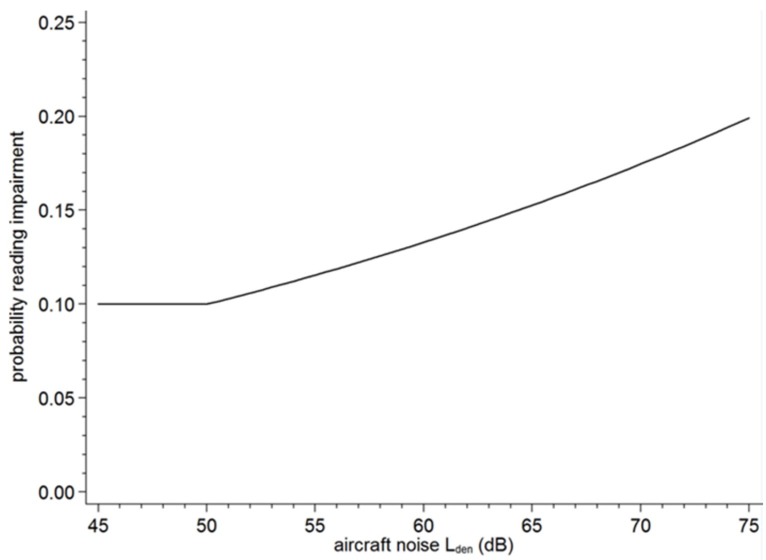

Figure 3. Probability of reading impairment among children 7-17 year old as function of L_{den} (aircraft noise) (adopted from: Clark et al, 2006 and Van Kempen, 2008).

2.5 Hypertension

In 2012 Van Kempen and Babisch (2012) carried out a meta-analysis in order to derive a quantitative exposure-response relation between road traffic noise and the prevalence of hypertension. Based on the results of 24 studies, carried out between 1970 and 2010, an odds ratio of 1.07 (95%CI: 1.02-1.12) per 10 dB increase in the 16 hour day-time road traffic noise level ($L_{Aeq,16hr}$) was derived. In 2009 Babisch and Van Kamp quantitatively summarised the results of 5 studies on aircraft noise and the prevalence of hypertension: an odds ratio of 1.13 (95%CI: 1.00-1.28) per 10 dB L_{den} increase in aircraft noise was estimated (Babisch and Van Kamp, 2009). The exposure range in the meta-analysis of Babisch and Van Kamp was 50 to 70 dB L_{den} and in the analysis of Van Kempen and Babisch was 45-75 dB $L_{Aeq,16hr}$. Since in agglomerations the L_{den} for road traffic noise is in general about 2 dB higher than the $L_{Aeq,16hr}$, we assumed for both noise sources that the increased risk for hypertension starts at 50 dB L_{den}.

Similar to reading impairment, there is a certain percentage of hypertension in the population in the absence of environmental noise. Its prevalence is for a large extent age and for a minor extent sex dependent, it is influenced by life-style factors (obesity, lack of exercise, diet, etc.) and differs between countries. The increased risk in hypertension due to noise can be described with a logistic model. In the model the risk for hypertension depends on the odds ratio, on the level of the noise exposure and on the 'base-line' prevalence. Given the age, sex and country dependency of the prevalence, we used the age and sex specific prevalence estimated for three different regions in Europe reported by Kearney et al (2005) as estimate for the 'base-line' prevalence. This approach leads to a variety of exposure-response relations that are applied to estimate the health impact of environmental noise on hypertension in the EEA33. Examples of these relations are given in Figure 4 for one of the three regions. Different than for reading impairment, we present in Figure 4 the additional probability due to noise.

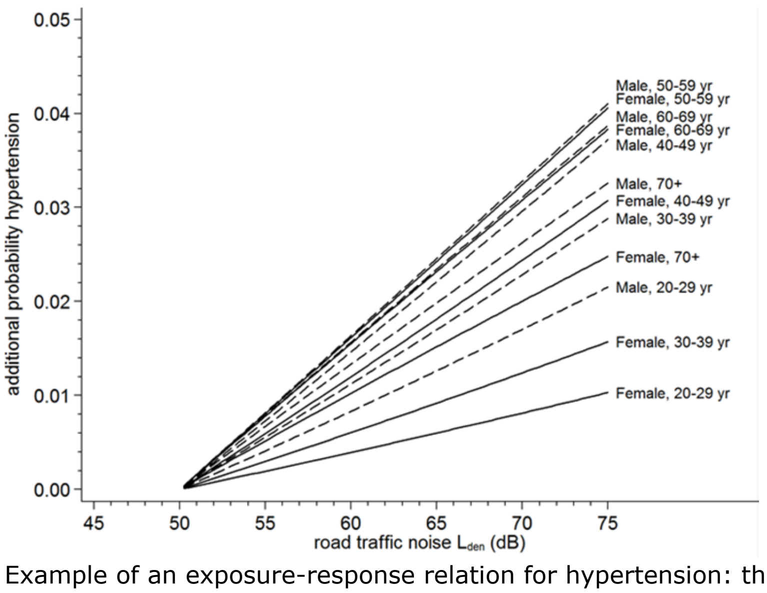

Figure 4. Example of an exposure-response relation for hypertension: the additional probability for hypertension in relation to exposure to road traffic noise, for different combination of age and sex in established market economies.

No pooled exposure-response relation is available for the association between railway or industry noise and the prevalence of hypertension. We used the

relation between road traffic noise (in L_{den}) and hypertension as an indication for the relation between railway noise (L_{den}) and hypertension and for the relation between industry noise (L_{den}) and hypertension.
Details about the implementation of the calculations for hypertension can be found in Annex 4.

2.6 Coronary heart disease and stroke

In the World Health Organization guidelines on community noise (WHO, 1999) it was concluded that epidemiological studies show that cardiovascular effects occur after long-term exposure to noise with $L_{Aeq,24hr}$ values of 65 – 70 dB. The $L_{Aeq,24hr}$ is the equivalent noise level over the 24 hour period. Since that time a number of studies have been published on the association between environmental noise and the incidence of coronary heart disease (including myocardial infarction) and stroke.

Recently the results of two meta-analyses were published (Vienneau et al 2013; Babisch, 2014). For their meta-analysis, Vienneau et al (2013) identified 8 cohort and case-control studies focusing on road and aircraft noise and the incidence and the mortality of coronary heart disease. The relative risk per 10 dB increase in L_{den} was 1.08 (95% CI: 1.03 – 1.14) for the incidence of coronary heart disease. For coronary heart disease mortality the relative risk was 1.04 (95% CI: 0.98 – 1.09). When both endpoints (incidence and mortality) were combined, the relative risk was 1.05 (95% CI: 1.02-1.09). The results suggest that the association starts as low as 50 dB L_{den} (Vienneau, personal communication). Babisch (2014) included in his meta-analysis the results of 14 studies investigating the association between road traffic noise exposure and coronary heart disease. Other than Vienneau et al (2013), Babisch included also the results of cross-sectional studies. After pooling the results of the evaluated studies, Babisch found a relative risk of 1.08 (95% CI: 1.04 – 1.13) per 10 dB increase within a noise exposure range of 52-77 dB L_{DN}. The L_{DN} is similar to the L_{den}; it lacks a penalty for the evening period. In an earlier study, Babisch (2008) derived a relative risk for males in the order of 1.17 per 10 dB for an exposure range of 57-77 dB.

Unfortunately there is no meta-analysis published that describes the relation between noise exposure and other cardiovascular end points than coronary heart disease. There is good evidence that hypertension is not only associated with a higher risk for coronary heart disease, but also with a higher risk for stroke. Since 2010 a number of studies have been published that investigated the association between noise exposure and the risk of stroke (Huss et al., 2010; Sørensen et al., 2011; Hansell et al., 2013; Correia et al., 2013, Floud et al., 2013, de Kluizenaar et al., 2013). To get an impression of the risk of environmental noise on the incidence and mortality, we carried out an 'ad-hoc' meta-analysis for stroke with the results of these 6 studies. For the combination of incidence and mortality, we found a relative risk of 1.04 (95%CI: 1.00-1.09) per 10 dB increase in noise exposure, which is similar to the risk for coronary heart disease reported by Vienneau et al. (2013).

We used (crude) country-specific incidence data on hospital discharges and mortality from the European Cardiovascular Disease Statistics (Nichols et al., 2012; Nichols et al., 2013) to assess the 'base-line' risks for coronary heart disease and stroke. Information about the disease burden associated with coronary heart disease and stroke (years lived with disability and years life lost) was obtained from the latest World Health Organization Global Health Estimates for 2011 (http://www.who.int/healthinfo/global_burden_disease).

We used the combined risk estimate of Viennaeau et al. for coronary heart disease incidence and mortality, since it is primarily based on incidence studies and only incidence data is used in this report for coronary heart disease. An indicative assessment was carried out for stroke with the (combined) relative risk that was derived from the 'ad-hoc' meta-analysis. The same relative risk and the same threshold (50 dB L_{den}) were applied for all noise sources. Details of the method are described in Annex 5.

2.7 In summary

The health and well-being effects for which an exposure-response relation based on a pooled analysis or a meta-analysis is available and that are applied in this report are summed up in Table 1. The estimations for annoyance, sleep disturbance and reading impairment were made for sub groups of the total population (adults and children 7-17 years old). For hypertension, coronary heart disease and stroke the results are reported for the total population.

Table 1. Core characteristics of the applied exposure-response relations.

Health and well-being effect	Population	Reference
(severe) annoyance	adults	road traffic and railways: Miedema & Oudshoorn (2001); industry: Miedema & Vos (2004b); aircraft: Janssen & Vos (2009)
(severe) sleep disturbance	adults	road traffic, railways and industry: Miedema & Vos (2007); aircraft: Janssen & Vos (2009)
reading impairment	7-17 year olds	only aircraft: adapted from Clarck et al. (2006)
hypertension	total population	road traffic, railways and industry: Van Kempen & Babisch (2012); aircraft: Babisch & Van Kamp (2009)
coronary heart disease (mortality & morbidity)	total population	all sources: Vinneau et al (2013)
stroke (mortality & morbidity)	total population	all sources: ad-hoc meta-analysis based on 6 studies

In the previous sections it is indicated that health effects can already occur at noise levels less than 55 dB L_{den} and 50 dB L_{night}. For reading impairment, hypertension, coronary heart disease and stroke it is suggested that the threshold for the onset of these health effects starts at 50 dB L_{den}; for annoyance the threshold is less than 40 dB L_{den} and for sleep disturbance less than 40 dB L_{night}. In this report, we are only able to carry out the health impact assessment for levels equal to or above 55 dB L_{den} and 50 dB L_{night}. As a consequence, the reported numbers and percentages are only relevant for the populations living at levels equal to or above 55 dB L_{den} and 50 dB L_{night} which underestimates the total impact of environmental noise in Europe.
The calculations were carried out per country; subsequently the results were aggregated to EEA33 (EU28 plus Iceland, Liechtenstein, Norway, Switzerland and Turkey).

3 Results

3.1 Noise exposure

Table 2 gives an overview of the number of residents with an exposure equal to or above 55 dB L_{den} or equal to or above 50 dB L_{night} in the available distributions for road traffic, railway, industry and aircraft noise of the second round of noise mapping (version August 2013).

Table 2. The number of residents with an exposure equal to or above 55 dB L_{den} or equal to or above 50 dB L_{night} in the available distributions for road traffic, railway, industry and aircraft noise of the second round of noise mapping (EEA33)

Noise source	Number of residents (* million)	
	>= 55 dB L_{den}	>= 50 dB L_{night}
Road traffic noise in agglomerations*	42,0	29,6
Noise from major roads outside agglomerations	28,1	17,7
Railway noise in agglomerations*	3,9	2,9
Noise from major railways outside agglomerations	3,5	2,0
Aircraft noise in agglomerations*	1,7	0,47
Aircraft noise outside agglomerations related to major airports	0,66	0,17
Industry noise in agglomerations	0,32	0,17

* Including major sources/airports

In the available data, in total about 80 million residents have an exposure of 55 dB L_{den} or higher to noise from roads, railways, aircrafts or industry; for L_{night} about 53 million residents were included in the assessments. These unequal numbers for L_{den} and for L_{night} reflects that the areas of assessment for L_{den} and L_{night} differ due to the application of cut-off values for L_{den} and L_{night} that are not in agreement with each other. Almost 90% of the included populations is related to the road traffic noise assessments.

3.2 Annoyance

In Table 3 the impact of the noise on annoyance and severe annoyance among adults is given. The results are expressed as absolute numbers as well as percentage (among adult residents above 55 dB L_{den}, not as percentage of the total population). In general, the fraction adults is about 80% of the total population.

Table 3. Prevalence of annoyance and severe annoyance among adults due to exposure equal to or above 55 dB L_{den} to four noise sources: percentage and number of cases (and 95% confidence interval) in thousand (EEA33)

Noise source	Annoyance		Severe annoyance	
	Percentage**	# of cases (*1,000)	Percentage**	# of cases (*1,000)
Road traffic noise in agglomerations*	32.2% [27,7 – 36,9]	10,880 [9,370 – 12,490]	14.9% [12.1 – 18.1]	5,040 [4,080- 6,140]
Noise from major roads outside agglomerations	29.0% [24.7 – 33.6]	6,510 [5,550 – 7,540]	12.8% [10.2 – 15.8]	2,880 [2,300 – 3,550]
Railway noise in agglomerations*	20.2% [16.2 – 24.9]	634 [508 - 779]	7.4% [5.4 – 9.8]	231 [170 - 306]
Noise from major railways outside agglomerations	17.4% [13.7 – 21.6]	491 [386 - 611]	6.0% [4.3 – 8.1]	169 [122 - 227]
Aircraft noise in agglomerations*	62.2% [56.0 – 68.6]	868 [781 - 958]	39.7% [33.7 – 46.7]	553 [470 - 652]
Aircraft noise outside agglomerations related to major airports	60.1% [53.7 – 66.7]	322 [288 - 358]	37.2% [31.4 – 44.4]	200 [168 - 238]
Industry noise in agglomerations	27.3% [23.3 – 32.1]	71 [61 - 84]	14.2% [11.4 – 17.7]	37 [30 - 46]

*Including major sources/airports; **Percentage calculated over the population adults living at levels equal to or above 55 dB L_{den} (the fraction adults is about 80% of the total population)

Almost 11 million adults living in agglomerations at levels equal to or above 55 dB L_{den} are annoyed by noise from road traffic noise; about half of them is severely annoyed. Road traffic noise exposure from major roads outside agglomerations leads to 6.5 million annoyed including almost 3 million severely annoyed adults. In comparison to road traffic noise, the other noise sources contribute less to the (severe) annoyance.
As indicated before, the reported numbers only reflect the health impact in the areas that were part of the noise mapping assessment and for which the data was included in the database of August 2013. The number of annoyed adults adds up in Table 3 to 19.8 million for all sources including 9.1 million with severe annoyance; this is an underestimation of the actual numbers in the EEA33.
Aircraft noise leads to the highest annoyance percentages; more than half of the population living at levels equal to or above 55 dB L_{den} is annoyed by aircraft noise. Forty percent is severely annoyed. The lowest percentages were obtained for railway noise. All percentages given in Table 3 refer to the population living at levels equal to or above 55 dB. The variation in the percentage between the noise sources are primarily caused by the differences between the exposure-response relations (see Figure 2; the percentage annoyance differs between sources at the same noise level) and to a much lesser extend to differences in the exposure distributions above 55 dB L_{den} of the various sources.

3.3 Sleep disturbance

Table 4 provides an estimate of magnitude of sleep disturbance due to noise exposure during the night. The results are expressed as absolute numbers as well as percentage (of the adult population exposed to ≥ 50 dB L_{night}).

Table 4. Prevalence of self-reported sleep disturbance and severe sleep disturbance among adults due to exposure equal to or above 50 dB L_{night} to four noise sources: percentage and number of cases (and 95% confidence interval) in thousands (EEA33)

Noise source	Sleep disturbance		Severe sleep disturbance	
	Percentage	# of cases (*1,000)	Percentage	# of cases (*1,000)
Road traffic noise in agglomerations*	13.8% [10.3 – 18.0]	4,670 [3,490 – 6,100]	6.4% [4.3 – 9.2]	2,170 [1,460 – 3,110]
Noise from major roads outside agglomerations	11.8% [8.8 – 15.5]	2,660 [1,980 – 3,490]	5.5% [3.7 – 7.9]	1,230 [822 – 1,760]
Railway noise in agglomerations*	7.2% [4.1 – 11.8]	225 [129 - 369]	2.8% [1.4 – 5.2]	87 [43 - 164]
Noise from major railways outside agglomerations	5.5% [3.2 – 9.0]	155 [89 - 254]	2.1% [1.1 – 4.0]	60 [30 - 112]
Aircraft noise in agglomerations*	10.1% [6.4 – 14.3]	141 [90 - 199]	6.7% [3.9 – 10.5]	94 [54 - 147]
Aircraft noise outside agglomerations related to major airports	9.2% [5.8 – 13.1]	49 [31 - 700]	6.1% [3.5 – 9.5]	33 [19 - 51]
Industry noise in agglomerations	10.6% [7.9 – 13.8]	28 [21 - 36]	5.0% [3.4 – 7.1]	13 [9 - 19]

*Including major sources/airports; **Percentage calculated over the population of adults exposed to ≥ 50 dB L_{night} (the fraction adults is about 80% of the total population)

It is estimated that about 7.3 million adults suffer from sleep disturbance due to road traffic noise; 3.4 million of them are highly sleep disturbed. About two-third of the impact is related to road traffic in agglomerations. The contribution of other sources is smaller. It is estimated that railway noise leads to 380 thousand sleep disturbed adults (almost 150 thousand are highly sleep disturbed) and aircraft noise to 190 thousand sleep disturbed adults (of which 125 thousand are severely sleep disturbed). Also for these two sources, the majority of the burden takes place in agglomerations. The numbers in Table 4 add up to 7.9 million adults that suffer from sleep disturbance, including 3.7 million that have severe sleep disturbance.

3.4 Reading impairment

For aircraft noise an exposure-response relation is available from the RANCH study for reading impairment among children. The impact of aircraft noise on reading impairment is described in Table 5. We also report the attributable percentage; this number reflects the percentage of children that suffer from reading impairment due to their exposure to aircraft noise out of the total number of children with reading impairment.

Table 5. Prevalence of reading impairment among children 7-17 years of age due to exposure to aircraft noise equal to or above 55 dB L_{den}: attributable percentage and additional number of cases (and 95% confidence interval) (EEA33)

Noise source	attributable percentage	additional # of cases
Aircraft noise in agglomerations*	24.2% [7.2 – 37.9]	5,900 [1,440 – 11,300]
Aircraft noise outside agglomerations related to major airports	22.1% [6.6 – 34.9]	1,920 [474 – 3,630]

*Including major airports

It is estimated that almost 8 thousand 7-17 year old school children have a reading impairment related to aircraft noise. This is almost a quarter of all children with reading impairment within the 55 dB L_{den} aircraft noise contour.

3.5 Hypertension

In Table 6 the impact of the noise on hypertension is given. The additional number of hypertension cases as well as the attributable percentage is estimated.

Table 6. Prevalence of hypertension due to exposure equal to or above 55 dB L_{den} to four noise sources: attributable percentage and additional number of cases (and 95% confidence interval) (EEA33)

Noise source	attributable percentage	additional # of cases
Road traffic noise in agglomerations*	3.8% [1.2 – 6.3]	497,000 [158,000 – 840,000]
Noise from major roads outside agglomerations	3.4% [1.1 – 5.6]	293,000 [93,000 – 494,000]
Railway noise in agglomerations*	3.7% [1.2 – 6.0]	44,100 [14,000 – 74,500]
Noise from major railways outside agglomerations	3.2 [1.0 – 5.3]	34,300 [10,900 – 57,900]
Aircraft noise in agglomerations*	5.3% [0.2 – 10.0]	29,000 [800 – 57,600]
Aircraft noise outside agglomerations related to major airports	4.8% [0.1 – 9.1]	10,200 [282 – 20,200]
Industry noise in agglomerations	2.9% [0.9 – 4.8]	2,880 [913 – 4,850]

*Including major sources/airports

From Table 6 it can be deduced that the noise exposure leads to about 910 thousand additional cases of hypertension. These are primarily related to road traffic noise (790 thousand: 87%). Railways noise is responsible for about 80 thousand, and aircraft noise for about 40 thousand additional cases of hypertension.

3.6 Coronary heart disease and stroke

In Table 7 the effect on noise on the incidence of coronary heart disease is given. The impact can be described as additional cases of hospital discharge and additional cases of mortality. Also the impact is described as additional years of living with a disability (YLD) as a consequence of having the underlying disease or as additional years of life lost (YLL) due to premature mortality due to the underlying disease. Again, we provide the attributable percentage of coronary heart disease for residents exposed to noise levels equal to or above 55 dB L_{den}. This percentage is (about) equal for all four effects that are described in Table 7. In Table 8 results for the implication of noise exposure for the incidence of stroke are given.

Noise could lead to a total of about 6,700 premature deaths per year due to coronary heart disease and about 3,300 premature deaths per year due to stroke. Road traffic noise is the main source: 8,900 of the 10,000 premature deaths per year (89%).
The total number of hospital discharges due to noise related coronary heart disease and stroke is about a four-fold higher than the number of premature deaths: 43 thousand per year.
It is estimated that about 3-6% of the mortality due to coronary heart disease or stroke among the population living at levels of 55 dB L_{den} or higher is associated with the exposure to environmental noise.

Table 7. Incidence of coronary heart disease (hospital discharges and mortality) and burden of disease (years of life lost due to disability and years of life lost due to premature mortality) due to exposure equal to or above 55 dB L_{den} from four noise sources: attributable percentage, additional number of cases and burden of disease per year (and 95% confidence interval) (EEA33)

Noise source	Hospital discharges	Mortality	Years of life lost due to disability	Years of life lost due to premature mortality	Attributable percentage for all separate endpoints
	additional # of cases/year	additional # of cases/year	total YLD/year	total YLL/year	
Road traffic noise in agglomerations*	17,700 [7,020- 32,100]	3,740 [1,480 - 6,790]	6,170 [2,450 – 11,200]	66,300 [26,300 – 121,000]	6.1% [2.5 – 10.5]
Noise from major roads outside agglomerations	9,220 [3,670 – 16,700]	2,170 [865 – 3,940]	3,620 [1,440 – 6,570]	32,400 [12,900 – 58,800]	5.4% [2.2% - 9.4%]
Railway noise in agglomerations*	1,590 [631 – 2,880]	324 [129 - 589]	540 [215 - 982]	4,880 [1,940 – 8,860]	5.8% [2.4 – 10.1]
Noise from major railways outside agglomerations	1,180 [470 – 2,140]	264 [105 - 479]	420 [167 - 761]	3,740 [1,490 – 6,770]	5.1% [2.1 – 8.9]
Aircraft noise in agglomerations*	537 [214 - 968]	124 [49 - 223]	187 [75 - 338]	2,080 [832 – 3,760]	4.6% [1.9 – 8.1]
Aircraft noise outside agglomerations related to major airports	186 [74 - 334]	39 [16 - 70]	64 [26 - 114]	574 [230 – 1,030]	4.1% [1.7 – 7.2]
Industry noise in agglomerations	104 [41 - 187]	25 [10 - 45]	36 [14 - 65]	413 [165 - 746]	4.6% [1.9 – 8.0]

*Including major sources/airports

Table 8. Incidence of cerebrovascular disease (hospital discharges and mortality) and burden of disease (years of life lost due to disability and years of life lost due to premature mortality) due to exposure equal to or above 55 dB L_{den} from four noise sources: attributable percentage, additional number of cases and burden of disease per year (EEA33).

Noise source	Hospital discharges	Mortality	Years of life lost due to disability	Years of life lost due to premature mortality	Attributable percentage for all separate endpoints
	additional # of cases/year	additional # of cases/year	total YLD/year	total YLL/year	
Road traffic noise in agglomerations*	7,380 [0 – 16,800]	1,950 [0 – 4,450]	3,610 [0 – 8,230]	27,500 [0 – 62,700]	4.9%
Noise from major roads outside agglomerations	3,850 [0 – 8,740]	1,020 [0 – 2,310]	2,230 [0 – 5,050]	13,500 [0 – 30,700]	4.4%
Railway noise in agglomerations*	659 [0 – 1,500]	140 [0 - 318]	331 [0 - 754]	2,030 [0 – 4,620]	4.7%
Noise from major railways outside agglomerations	503 [0 – 1,140]	107 [0 - 242]	259 [0 - 587]	1,560 [0 – 3,530]	4.1%
Aircraft noise in agglomerations*	225 [0 - 508]	62 [0 - 140]	109 [0 - 245]	865 [0 – 1,950]	3.7%
Aircraft noise outside agglomerations related to major airports	85 [0 - 190]	17 [0 - 39]	39 [0 - 88]	240 [0 - 539]	3.3%
Industry noise in agglomerations	45 [0 - 102]	11 [0 - 25]	21 [0 - 47]	171 [0 - 387]	3.7%

*Including major sources/airports

4 Discussion

We assessed the health implication of environmental noise in the EEA33 making use of the available results of the second round of noise mapping in the framework of the END (version August 2013). The results indicate that an estimated 19.8 million adults are annoyed due to noise from road traffic, railways, aircrafts or industry; 9.1 million of them are highly annoyed. It is estimated that 7.9 million adults suffer from noise related sleep disturbance due to these sources. Almost half of them (3.7 million) are severely sleep disturbed. We estimate that the evaluated noise sources contribute to almost 900 thousand additional prevalent cases of hypertension. Since hypertension is an important risk factor for cardiovascular disease and premature mortality, we foresee that this leads to 43 thousand additional cases each year of hospital admissions and to 10 thousand cases of premature mortality each year due to coronary heart disease and stroke. About 90% of the health impact is due to exposure to road traffic noise.

As far as we are aware, this is the first assessment at the European level in which the health implications of noise from road traffic, railways, aircrafts and industry are described, using the same methodology and the latest insights about the health effects of environmental noise. Nevertheless, this assessment is hampered by a number of issues.
The main limitation is that second round of noise mapping is by far complete. The completeness in the database of August 2013 is 62% for road traffic noise in agglomerations, 59% for railway noise, 44% for aircraft noise and 56% for industry noise. Outside agglomerations, the completeness is 36% for major roads, 36% for major railways and 95% for major airports (Blanes et al., in preparation).
The exposure-response functions used in this report indicate that additional risks due to environmental noise exposure can already occur at levels below 55 dB L_{den} or below 50 dB L_{night}, the lower limits of the noise assessment in the framework of the END. The consequence is that the health impact of the local sources that are considered in the noise assessment for END are not fully captured. For annoyance and sleep disturbance, the effects below 55 dB L_{den} or below 50 dB L_{night} are ignored. For hypertension, hospital admissions and premature mortality, the health impact in the population living between 50 and 55 dB L_{den} is not included.
Third, the exposure distributions of local sources not considered in the framework of END are unknown, for example noise exposure in smaller agglomerations is not addressed by the END.

At the time of writing it is not possible to quantify the impact of these limitations on the results. Therefore, it is unknown which proportion of the population with a relevant noise exposure in the EEA33 is not included in the calculations of this report. As a consequence, it is not possible to estimate at this stage the full health implications of noise in the EEA33, nor do we know how much we cover with the reported estimates. In a previous (unpublished) study (personal communication by Lercher, De Kluizenaar and Houthuijs, 2012), the health impact of road traffic noise in the total population of the EU27 (500 million residents) was calculated using the noise distribution based on the first round of noise assessment in the framework of END supplemented with estimated exposure distributions for urban areas not covered by END (according to De Vos and Van Beek, 2011) and for rural areas (educated guess). At that time, it was estimated that about 27 million adults were severely annoyed by road traffic noise; in the current assessment the estimation is about 8 million. For premature mortality, the results are 34 thousand based on the full exposure distribution against 9 thousand in the current assessment. This indicative

comparison suggests that the current assessment may reflect 20-35% of the total impact of road traffic noise in the EEA33. The magnitude of underestimation is not known for other sources of noise. An expert guess based on the incomplete data set results in approximately 30 thousand premature deaths due to road, railway and aircraft noise for the total population in the EEA 33 member states. Estimation of the annoyed and sleep disturbed population is much more difficult, since these effects starts at lower exposure levels.
It is recommended to investigate if it possible to assess the full distribution of L_{den} and L_{night} among the population of the EEA33 by making use of a combination of data collected in the framework of the END and estimations for missing areas and noise bands to get an impression of the magnitude of underestimation for the various noise sources.

An assessment of the quality of the noise data and the consequences of possible differences in methods and models between countries is beyond the scope of this report. We presume that the incompleteness of the database has more influence on the results of the health impact assessment than the quality of the current available data.

We implemented the source-specific ‘generalised’ exposure response functions for annoyance and sleep disturbance slightly different than for example in the recent World Health Organization report on the burden of disease due to environmental noise (WHO, 2011) by using more precise equations, by applying updated equations and by limiting the effected population to adults. Only an exposure response relation for industry noise in relation to sleep disturbance was lacking; we used the relation for road traffic noise as replacement. Given the relatively small contribution of industry noise to the total health burden, this has a limited effect on the overall number of sleep disturbed residents. Since no exposure-response functions for the younger age groups are available, it is difficult to estimate how many cases of annoyance and sleep disturbance are overlooked by this approach. In general, we ignored the age-dependency of annoyance and sleep disturbance. There are clear indications that residents in middle age are more annoyed found than the younger and oldest age fractions of the general population (Van Gerven et al., 2009). Also the association of noise-related sleep disturbance with age has an inverse U-shape, with the highest probabilities found between 50 and 56 years of age (Miedema and Vos, 2004b).
As was indicated in Figure 2 by showing the tolerance intervals of the ‘generalised’ relations for road and railway noise, there is an underestimation in the possible deviation of exposure-response relations for ‘local’ situations when ‘generalised’ exposure response functions are applied. Unfortunately, it is not known if ‘local’ means variation between locations/regions in a country, variation between countries, or both and how this could affect the overall estimate in Europe, since country-specific exposure-response relations are in general lacking. Only for some specific international airports in Europe, for example Frankfurt and Zurich, separate exposure response relations have been published and applied (Brink et al., 2010). It would be worthwhile for future assessments to compare the results of different implementations of exposure response functions for annoyance and sleep disturbance on the overall estimate in Europe.

The exposure response relations for hypertension, coronary heart disease and stroke were derived from risk estimates from meta-analyses carried out after 2008 in combination with information about baseline region-specific prevalences (hypertension) or country specific incidence (coronary heart disease and stroke) and country specific demographic information. It is striking that this approach leads to exposure-response relations for mortality due to coronary heart disease that can differ between countries up to more than a factor 6 in additional risks at the same noise level as is illustrated in Annex 5 (Figure A7). The reason for this variation in exposure response function is the reported variability in country specific baseline incidence. The hospital discharge rates for coronary heart disease and stroke are an indirect approximation of the morbidity; they are not a true measure of the incidence of these disease. Differences between countries in baseline 'incidence' are influenced by variation between countries in the healthcare system as well as by rates of acute death without hospital admission. In general, there is a lack of high quality and comparable incidence and mortality data on cardiovascular endpoints across Europe, so it is difficult to judge whether the large difference between the exposure-response relations between countries reflects real differences in the risks of noise for cardiovascular disease in these countries. The studies included in the meta-analyses on cardiovascular disease and stroke origin from Western Europe and North America. It is not known if risk estimates from these meta-analyses are applicable for all countries in the EEA33, given the differences in baseline incidence between countries.

Other than for annoyance and sleep disturbance, noise only explains a small part of the variation in cardiovascular disease incidence and mortality. For this reason, the uncertainties in the results of meta-analyses on cardiovascular disease incidence and mortality are much larger than is the case for annoyance and sleep disturbance. As a consequence, a large number of studies on this kind of health endpoints is needed to obtain pooled effect estimates with limited uncertainty. The number of studies on cardiovascular disease incidence and mortality is relatively small, so we pooled the results on disease incidence and mortality with the assumption that the effect estimates for disease incidence and for mortality are similar. Given the limited number of studies, no distinction could be made between noise sources, except for hypertension where separate exposure response relations are available for road traffic noise and for aircraft noise. In the case of hypertension, we assumed that the exposure-response relations for railway and industry noise are equal to the one for road traffic noise. Given the public health implications of the effects of noise on the cardiovascular system, there is a need for new studies in this field: 1) to (further) disentangle the separate influence of noise and the coexisting co-exposures like traffic related air pollution; 2) to assess if there are differences in risk between noise sources similar to the differences found for annoyance and sleep disturbance; and 3) to explore if the large variability in country specific baseline incidences for coronary heart disease and stroke also leads to true variation in exposure-response relations for environmental noise between regions in Europe.

The reported size of the noise related health impacts have uncertainties that are only partly reflected in the reported 95% confidence intervals. The major sources of uncertainties are, in addition to the statistical uncertainties in the exposure response relations, the transferability of the (often international) relations to individual countries of the EEA33, the comparability of the baseline prevalence and incidence data on hypertension, coronary heart disease and stroke between countries and the assumptions about the demographic build-up of the areas where the noise assessment took place. The importance and the magnitude of the uncertainties is likely to vary between health endpoints and between countries. At this stage, it is not possible to assess the magnitude of these uncertainties.

The considered health effects in this report (annoyance, sleep disturbance, cognitive impairment and cardiovascular health) are the most investigated non-auditory health endpoints of noise exposure. It cannot be excluded that other health endpoints are related to noise exposure as well. Two recent cohort studies in Denmark investigated the risk of environmental noise on the incidence of diabetes and of breast cancer (Sørensen et al, 2013; Sørensen et al., 2014). Both health effects may relate to excess of stress hormones and reduced sleep quality. Exposure to road traffic noise was associated with a higher risk of type 2 diabetes (Sørensen et al, 2013), and exposure to road traffic and railway noise was associated with an increased risk of estrogen receptor negative breast cancer (Sørensen et al, 2014). Although the outcomes of these studies should be treated with care since the results need conformation in other studies, the findings are biologically plausible and suggest that in future health impacts assessments additional health effects of noise may have to be considered.

We have reported the number of residents affected by noise exposure separately for a number of health endpoints. There are integrated health measures that can express different health endpoints in the same unit, like DALY's (Disability Adjusted Life Years). The DALY combines the impact described as additional years of living with a disability (YLD) as a consequence of having the underlying disease or as additional years of life lost (YLL) due to premature mortality due to the underlying disease. Recently, the World Health Organization reported the burden of disease of noise in Europe in DALY's (WHO, 2011). We did not express the burden of disease in DALY's in this report, since the size of the affected population is based on two different noise assessments (L_{den} for annoyance, cognitive impairment, hypertension and cardiovascular disease, and L_{night} for sleep disturbance). Since different populations are included in the L_{den} (about 80 million residents) and in the L_{night} assessment (about 53 million residents) 'adding up' the health effects is not informative. Sleep disturbance among residents living between 50 dB L_{den} and 55 dB L_{night} is ignored in such an aggregation of effects.
This observation leads to the recommendation that consideration should be given to concentrate the noise assessment in the framework of the END over a fixed area - preferable defined by an administrative boundary - if reporting on the health consequences is one of the objectives of the assessment. With this approach, the subsequently derived noise distributions for L_{den} and L_{night} are related to the same population, so a complete set of health effects can be calculated for this group of residents. If the area is defined on the basis of a noise contour, it is plausible to take the L_{den} as leading indicator, since the L_{night} is already part of the L_{den}. Subsequently, the lower limit of the L_{night} should then not be restricted to a certain noise level (cut-off point).
The meta-analyses on hypertension (Babisch and Van Kamp, 2009; Van Kempen and Babisch, 2012) suggest a threshold value of 55 L_{den} or lower. For coronary heart disease, Vienneau et al (2013) reports 50 dB L_{den} and Babisch (2014) 52 dB L_{DN} as threshold value. Since these threshold values are below the current lower limit of the noise assessment for L_{den} (55 dB), it is recommended to decrease the lower limit of 55 dB to 50 dB L_{den} or lower and preferably to 40 dB L_{den} given the probability of (severe) annoyance at 40 dB L_{den}. According to the World Health Organization night time noise guidelines for Europe, the L_{night} should not exceed 40 dB given the effects on sleep disturbance (WHO, 2009). This level of 40 dB L_{night} broadly corresponds with a level of 50 dB L_{den}.

5 Conclusions

The health implications of environmental noise in the EEA33 can be described as the number of adults with (severe) annoyance and (severe) sleep disturbance, as the number of children with reading impairment attributable to noise and the number of residents with hypertension, hospital admissions due to cardiovascular disease and the occurrence of premature mortality.

Based on the available data of the second round of noise mapping (August 2013), it is estimated that at least 19.8 million adults are annoyed due to noise from road traffic, railways, aircrafts or industry; 9.1 million of them are highly annoyed. 7.9 Million adults are expect to suffer from noise related sleep disturbance; 3.7 million of them are severely sleep disturbed. Environmental noise exposure contributed to almost 900 thousand additional prevalent cases of hypertension in 2012, to 43 thousand additional cases each year of hospital admissions and to 10 thousand cases of premature mortality each year due to coronary heart disease and stroke. Almost 90% of the health impact is related to road traffic noise exposure.

The current assessment may reflect only 20-35% of the total impact of road traffic noise in the EEA33. Incomplete data from countries, limitation of the noise assessment to agglomerations and major sources and to levels above 55 dB L_{den} or above 50 dB L_{night} are the causes of the underestimation. The size of the underestimation is not known for other sources of noise. An expert guess, based on the incomplete data sets, leads to approximately 30 thousand premature deaths due to road, railway and aircraft noise for the total population in the EEA 33 member states. It is recommended to investigate if it possible to quantify the lack of information per cause and per noise source, and to assess the impact of the lack of information on the reported numbers

The reported numbers encompass many uncertainties. The major sources of uncertainties are in the exposure response relations, the transferability of the (often international) relations to individual countries of the EEA33, the comparability of the baseline data on hypertension, coronary heart disease and stroke between countries and the assumption about the demographic build-up of the areas where the noise assessment took place. The importance and the magnitude of the uncertainties vary from health endpoint to health endpoint. Also, the health impact assessment reflects the current stage of knowledge; it cannot be excluded that in the near future other health endpoints - like for example diabetes - will be linked to noise exposure.

To improve the assessment of health implications of environmental noise, we have identified some potential points of improvement for the noise assessment in the framework of the END that might be considered for application in future noise assessments.

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Annex 1: Annoyance

The source-specific exposure-response equations for (severe) annoyance are given in Table A1 and Figure A1.

Table A1. Exposure-response functions for (severe) annoyance in relation to L_{den} for road traffic, railway, aircraft and industry noise

Noise source	$\int_{annoyance}(L_{den})$
Road traffic	1-normal((A-(-106.97+(L_{den})*(2.22)))/sqrt(150.54+1150.71))
Railway	1-normal((A-(-110.09+(L_{den})*(2.10)))/sqrt(53.86+1078.73))
Aircraft	1-normal((A-(-93.29+(L_{den})*(2.61)))/sqrt(75.30+1303.21))
Industry	1-normal((A-(-126.52+(L_{den})*(2.49)))/sqrt(2054.43))

For annoyance A=50; for severe annoyance A=72

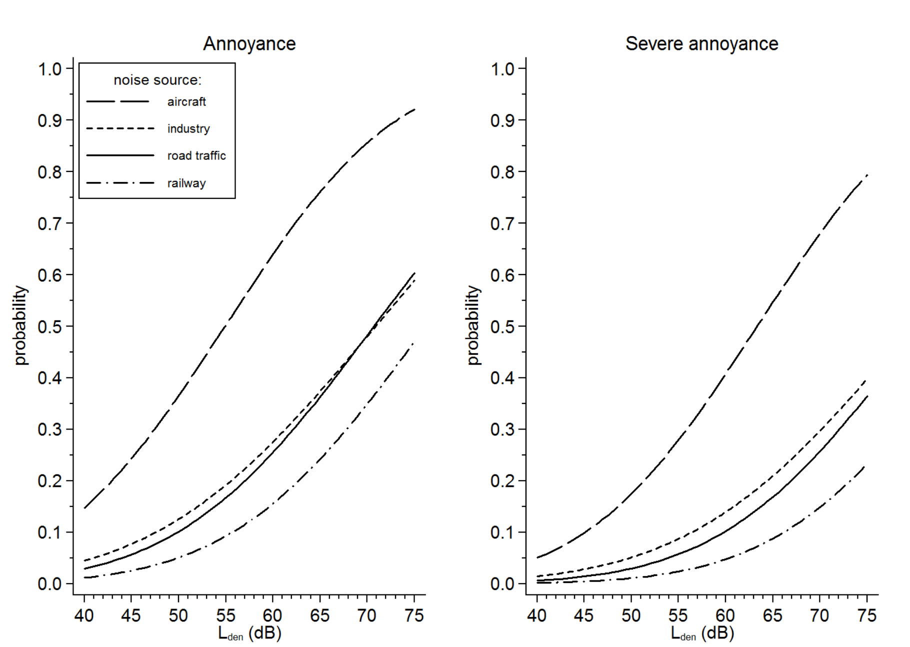

Figure A1. Probability of annoyance and severe annoyance from aircraft, industry, road traffic and railway noise as function of L_{den} (source: Miedema and Oudshoorn, 2001; Miedema and Vos, 2004a; Janssen en Vos, 2009)

The number of adults with (severe) annoyance for noise from a specific source per dB L_{den} can be calculated per country with the following equation:

$$n_{annoyance}(L_{den},c) = n_{inhab}(L_{den}) * f_{adults}(c) * \int_{annoyance}(L_{den},source)$$

with:

$n_{annoyance}(L_{den},c)$ number of annoyed adults per dB L_{den}
$n_{inhab}(L_{den})$ number of inhabitants per dB L_{den}
$f_{adults}(c)$ fraction adults, country specific (see Annex 6)
$\int_{annoyance}(L_{den},source)$ source-specific exposure-response equation for (severe) annoyance (Table A1)

The total number of adults with (severe) noise annoyance from a specific source is per country:

$$\sum_{Lden=55}^{75} n_{annoyance}\,(L_{den}, c)$$

The percentage of adults with (severe) noise annoyance from a specific source is per country:

$$\frac{100 * \sum_{Lden=55}^{75} n_{annoyance}\,(L_{den}, c)}{\sum_{Lden=55}^{75} n_{inhab}(L_{den}, c) * f_{adults}(c)}$$

The percentage of adults with (severe) noise annoyance from a specific noise source for the EEA33 is:

$$\frac{100 * \sum_{c=1}^{33} \sum_{Lden=55}^{70} n_{annyance}\,(L_{den}, c)}{\sum_{c=1}^{33} \sum_{Lden=55}^{70} n_{inhab}(L_{den}, c) * f_{adults}(c)}$$

Since the noise mapping in the framework of the END is reported between 55 and 75 dB L_{den}, the summation and the percentage is restricted for the population adults between 55 and 75 dB L_{den}.

Annex 2: Sleep disturbance

The source-specific exposure-response equations for (highly) sleep disturbed are given in Table A2 and Figure A2. For industry noise we used the relation for road traffic noise, since a source specific relation is lacking.

Table A2. Exposure-response functions for (highly) sleep disturbed in relation to L_{night} for road traffic, railway, aircraft and industry noise

Noise source	$\int_{sleepdisturbance}(L_{night})$
Road traffic (and industry)	1-normal((SD-(-90.70+(L_{night})*(1.80)))/sqrt(1789+272))
Railway	1-normal((SD-(-90.70+(L_{night})*(1.43)))/sqrt(1789+272))
Aircraft	1-normal((SD-(-159.34+82.10+(L_{night})*(1.97)))/sqrt(3102+768))

For sleep disturbed SD=50; for highly sleep disturbed SD=72

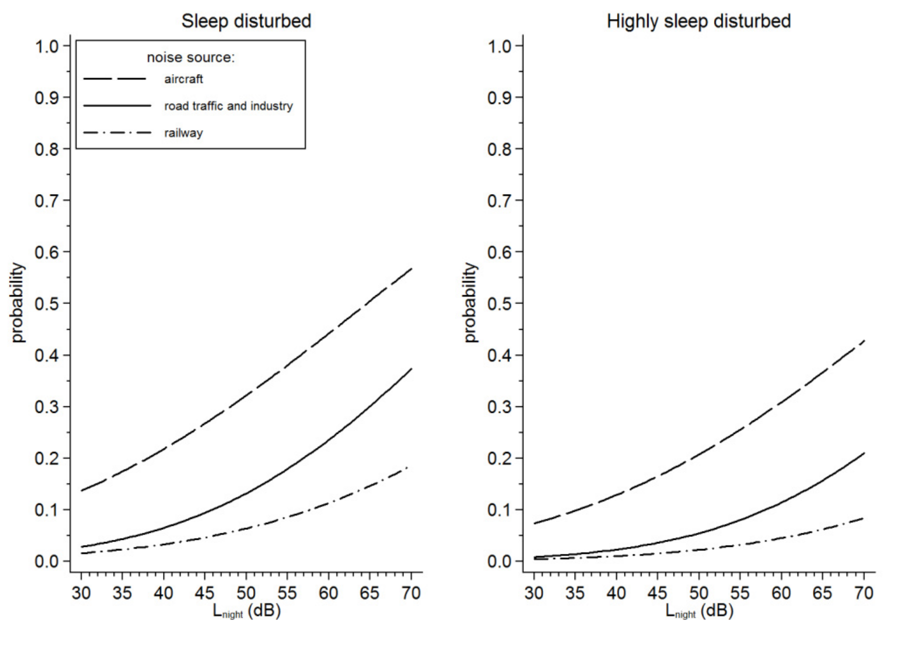

Figure A2. Probability of sleep disturbed and highly sleep disturbed from aircraft, road traffic and railway noise as function of L_{night} (source: Miedema and Vos, 2004b; Janssen en Vos, 2009).

The number of adults with (highly) sleep disturbance for noise from a specific source per dB L_{night} can be calculated per country with the following equation:

$$n_{sleepdisturbance}(L_{night}, c) = n_{inhab}(L_{night}) * f_{adults}(c) * \int_{sleepdisturbance}(L_{night}, source)$$

with:

$n_{sleepdisturbance}(L_{night}, c)$	number of sleep disturbed adults per dB L_{night}
$n_{inhab}(L_{night})$	number of inhabitants per dB L_{night}
$f_{adults}(c)$	fraction adults, country specific (see Annex 6)
$\int_{sleepdisturbance}(L_{night}, source)$	source-specific exposure-response equation for (highly) sleep disturbed (see Table A2)

The total number of adults with (highly) sleep disturbance from a specific noise source is per country:

$$\sum_{Lnight=50}^{70} n_{sleepdisturbance}\,(L_{night}, c)$$

The percentage of adults with (highly) sleep disturbance from a specific noise source is per country:

$$\frac{100 * \sum_{Lnight=50}^{70} n_{sleepdisturbance}\left(L_{night}, c\right)}{\sum_{Lnight=50}^{70} n_{inhab}\left(L_{night}, c\right) * f_{adults}(c)}$$

The percentage of adults with (highly) sleep disturbance from a specific noise source for the EEA33 is:

$$\frac{100 * \sum_{c=1}^{33} \sum_{Lnight=50}^{70} n_{sleepdisturbance}\left(L_{night}, c\right)}{\sum_{c=1}^{33} \sum_{Lnight=50}^{70} n_{inhab}\left(L_{night}, c\right) * f_{adults}(c)}$$

Since the noise mapping in the framework of the END is reported between 50 and 70 dB L_{night}, the summation and the percentage is restricted for the population adults between 50 and 70 dB L_{night}.

Annex 3: Reading impairment

In order to estimate the impact of noise exposure on children's cognitive functioning, we used the results of the European Fifth Framework Project RANCH (Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health: Exposure-effect relationships and combined effects). As part of the RANCH project, a cross-sectional field study was carried out investigating the effects of aircraft and road traffic noise on cognition, annoyance, behaviour and health in children attending primary schools around three airports in the United Kingdom, Spain and The Netherlands. Aircraft noise was amongst others found to be linearly related to a statistically significant decrease in reading comprehension levels. In RANCH, reading comprehension was measured by means of nationally standardized tests. In order to be able to make comparisons between each country's test, Z-scores were computed. The average effect of noise on an average child was demonstrated by means of calculating the reading delay: it was estimated that a 5 dB difference in aircraft noise was equivalent to a 1-month reading delay in the Netherlands and a 2-month reading delay in the United Kingdom.
Expressing the impact in terms of an average effect or as a sum of effects is not common in health impact assessments. Instead of an exposure-effect relation, we tried to derive an exposure-response relation. In the Netherlands, the results of school-tests (including reading comprehension) are expressed in terms of A, B, C, D or E level. The A-level refers to the 25% best scoring pupils. The E-level refers to 10% of the pupils with the lowest scores and indicates that pupil's performance is weak to very weak compared to peers. The E-level can be used as an indicator for "reading impairment". In the case that aircraft noise exposure does not affect reading comprehension, the proportion children with reading impairment will be on average 10%. This proportion rises with increasing exposure to aircraft noise.
For the probability of reading impairment, a new relationship was derived using the RANCH data. 'Reading impairment' was defined as the lowest 10 percentile of the reading scores of the children exposed to noise levels under 50 dB. Aircraft noise exposure at school was significantly related to the probability of a (very) low test score: in schools in areas with high aircraft noise exposure, the proportion children with a low test result on the reading comprehension test was significantly higher. After adjustment for confounders an odds ratio per 10 dB of 1.38 (95%CI 1.09 – 1.75) was estimated per 10 dB change in aircraft noise level (adopted from Van Kempen, 2008).

The exposure-response function for reading impairment is given in Table A4 and Figure A3.

Table A3. Exposure-response function for reading impairment in relation to L_{den} for aircraft noise.

$\int_{reading}(L_{den})$
$1/(1+\exp(-(\ln(f_{baseline}/(1-f_{baseline}))+(\ln(OR)/10*(L_{den}-Threshold)))))$ if $L_{den} \geq Threshold$ $f_{baseline}$ if $L_{den} < Threshold$ With: OR=1.38 per 10 dB with 95%CI: 1.09 – 1.75 $f_{baseline}=0.1$ Threshold=50 dB L_{den}

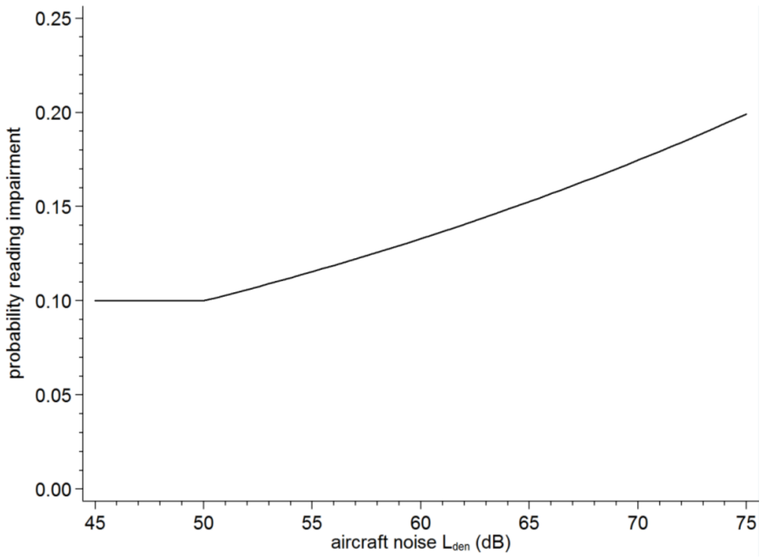

Figure A4. Probability for reading impairment as function of L_{den} (aircraft noise) (adopted from Clark et al, 2006; Van Kempen, 2008).

The number of children 7-17 years old with a reading impairment per country can be calculated for aircraft noise per dB L_{den} with the following equation:

$$n_{reading}(L_{den},c) = n_{inhab}(L_{den}) * f_{7\text{-}17yr}(c) * \int_{reading}(L_{den},aircraft)$$

with:

$n_{reading}(L_{den},c)$	number of children 7-17 year old with reading impairment per dB L_{den} per country
$n_{inhab}(L_{den},c)$	number of inhabitants per dB L_{den} per country
$f_{7\text{-}17yr}(c)$	fraction children 7-17 year old, country specific (see Annex 6)
$\int_{reading}(L_{den},aircraft)$	exposure-response equation for reading impairment associated with aircraft noise (see Table A3)

The total number of children 7-17 years old with a reading impairment per country is:

$$N_{reading,noise}(c) = \sum_{Lden=55}^{75} n_{reading}\,(L_{den},c)$$

In the case of absence of noise, the expected total number of children 7-17 years old with a reading impairment is per country:

$$N_{reading,no\ noise}(c) = \sum_{Lden=55}^{75} n_{inhab}\,(L_{den},c) * f_{7-17yr}(c) * f_{baseline}$$

The attributable percentage per country is the number of cases associated with noise exposure as percentage of the total number of cases:

$$\frac{100 * (N_{reading,noise}(c) - N_{reading,no\ noise}(c))}{N_{reading,noise}(c)}$$

The attributable percentage over the EEA33 (33 countries) is the number of cases associated with noise exposure as percentage of the total number of cases:

$$\frac{100 * (\sum_{c=1}^{33} N_{reading,noise}\,(c) - \sum_{c=1}^{33} N_{reading,no\ noise}\,(c))}{\sum_{c=1}^{33} N\,reading,noise(c)}$$

Since the noise mapping in the framework of the END is reported between 55 and 75 dB L_{den}, the summation and the attributable percentage is restricted for the population children 7-17 years old living at levels equal to or above 55 dB L_{den}.

Annex 4: Hypertension

The implementation of the (logistic) exposure-response function for hypertension is similar to the one for reading impairment. However, the base-line prevalence is not fixed but depends on age, sex and the region in Europe. In addition, the odds ratio for aircraft noise is different than the odds ratio used for other noise sources.
Table A4 describes the exposure-response function for hypertension. Table A5 gives the base-line prevalence per age, sex and region.

Table A4. Source specific exposure-response function for hypertension in relation to L_{den}.

$\int_{hypertension}(L_{den})$
$1/(1+\exp(-(\ln(f_{baseline}(a,s,r)/(1-f_{baseline}(a,s,r)))+(\ln(OR_{source})/10*(L_{den}-Threshold)))))$ if $L_{den} \geq Threshold$ $f_{baseline}(a,s,r)$ if L_{den} <threshold With: OR_{source}=1.13 per 10 dB for aircraft noise and OR_{source}=1.07 per 10 dB for other noise sources $f_{baseline}(a,s,r)$: base-line prevalence of hypertension per age and sex group and region (see Table A5) Threshold=50 dB L_{den}

Table A5. Base-line prevalence of hypertension per age and sex group and region (Kearney et al., 2005).

Group	Description	Region*		
		Established market economies	Former socialist economies	Middle eastern crescent
1	Males, 20–29 yr	0.144	0.187	0.112
2	Males, 30–39 yr	0.212	0.280	0.141
3	Males, 40–49 yr	0.326	0.341	0.261
4	Males, 50–59 yr	0.448	0.416	0.372
5	Males, 60–69 yr	0.603	0.537	0.466
6	Males, ≥70 yr	0.712	0.645	0.517
7	Females, 20–29 yr	0.062	0.032	0.051
8	Females, 30–39 yr	0.099	0.096	0.120
9	Females, 40–49 yr	0.233	0.292	0.281
10	Females, 50–59 yr	0.420	0.458	0.483
11	Females, 60–69 yr	0.613	0.753	0.606
12	Females, ≥70 yr	0.803	0.918	0.679

*refers to World Bank (1993): see Annex 6 for classification of EEA33 countries per region

Figure A5 describes the probability and additional probability for hypertension as function of L_{den} for different combinations of age and sex groups. As example, we have plotted the functions for road traffic noise in countries with established market economies.

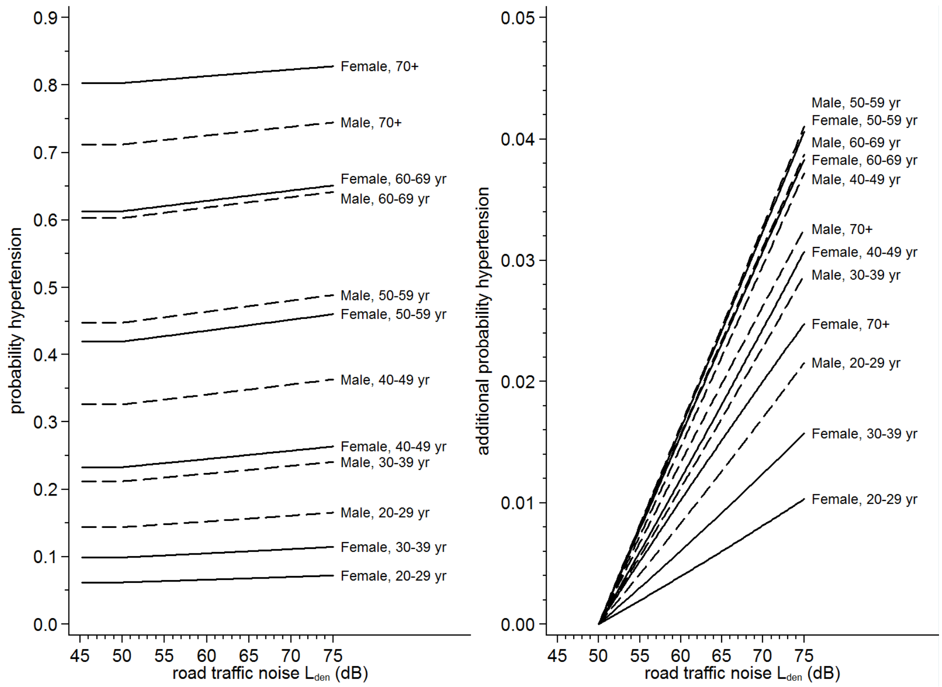

Figure A5. Probability (left) and additional probability (right) for hypertension as function of L_{den} (road traffic noise), for different age and sex groups in established market economies

The age and sex group specific numbers of residents with hypertension can be calculated per decibel per country with the following equation. In total, there are 12 groups (see Table A5):

$$N_{hyper}(L_{den},group,c) = n_{inhab}(L_{den},c) * f(group,c) * \int_{hypertension}(L_{den}, group,r)$$

with:

$n_{hyper}(L_{den},group,c)$	age and sex group specific numbers of residents with hypertension per dB L_{den} per country (12 groups)
$n_{inhab}(L_{den}, c)$	number of inhabitants per dB L_{den} per country
$f(group,c)$	fraction of specific age and sex group, country specific (see Annex 6)
$\int_{hyper}(L_{den},group,r)$	exposure-response equation for hypertension, age and sex group and region dependent (see Table A4)

The total number of residents with hypertension per country is:

$$N_{hyper,noise}(c) = \sum_{Lden=55}^{75} \sum_{group=1}^{12} n_{hyper}(L_{den}, group, c)$$

In the case of absence of noise, the expected total number of residents with hypertension per country is:

$$N_{hyper,no\ noise}(c) = \sum_{Lden=55}^{75} \sum_{group=1}^{12} n_{inhab}(L_{den}, c) * f\ (group, c) * f_{baseline}(group, r)$$

The attributable percentage per country is the number of cases associated with noise exposure as percentage of the total number of cases:

$$\frac{100 * (N_{hyper(c),noise} - N_{hyper(c),no\ noise})}{N_{hyper(c),noise}}$$

The attributable percentage over the EEA33 (33 countries) is the number of cases associated with noise exposure as percentage of the total number of cases:

$$\frac{100 * (\sum_{c=1}^{33} N_{hyper,noise}(c) - \sum_{c=1}^{33} N_{hyper,no\ noise}(c))}{\sum_{c=1}^{33} N\ hyper, noise(c)}$$

Since the noise mapping in the framework of the END is reported between 55 and 75 dB L_{den}, the summation and the attributable percentage is restricted for the population living at levels equal to or above 55 dB L_{den}.

Annex 5: Coronary heart disease and stroke

For coronary heart disease and stroke we expressed the burden of disease in relation to the noise exposure with four measures:

- The incidence of events by making use of data on hospital discharges
- The cause-specific mortality
- The years of life lost due to disability (YLD)
- The years of life lost due to premature mortality (YLL)

It is common in burden of disease studies to make use of the population attributable fraction (PAF). The PAF is 'the proportional reduction in population disease or mortality that would occur if exposure to a risk factor were reduced to an alternative ideal exposure scenario'.
The PAF per country can be calculated with the following equation:

$$PAF(c) = \frac{\sum_{Lden=0}^{75} f_{inhab}(Lden, c) * RR(Lden) - \sum_{Lden=0}^{75} f_{inhab}(Lden_{alt}, c) * RR(Lden)}{\sum_{Lden=0}^{75} f_{inhab}\,(Lden, c) * RR(Lden)}$$

with:

$f_{inhab}(L_{den}, c)$	fraction of inhabitants per dB L_{den} per country
$f_{inhab}(L_{den,alt}, c)$	fraction of inhabitants per dB L_{den} per country in alternative ideal exposure scenario
$RR(L_{den})$	Relative Risk at exposure level L_{den}

If we assume that an ideal exposure scenario does not lead to an excess risk (RR=1), the equation can be written as:

$$PAF(c) = \frac{\sum_{Lden=0}^{75} f_{inhab}(Lden, c) * (RR(Lden) - 1)}{(\sum_{Lden=0}^{75} f_{inhab}\,(Lden, c) * (RR(Lden) - 1)) + 1}$$

In the next step, the number of attributable cases per year can be calculated:

$$\text{PAF(c)} * \text{incidence(c)}$$

With:

incidence(c)	incidence of disease characteristic per year per country

We calculated the disease burden in a slightly different manner to stay more in line with the calculation for reading impairment and hypertension. The disadvantage is that the results slightly overestimates the attributable number of cases and slightly underestimate the population attributable fraction. However, the main advantage is that we can use the method for scenario calculation, since the approach describes above assumes that the total incidence remains equal in all scenario's.

For the relative risk for coronary heart disease we used the estimated for the combination of incidence and mortality reported by Vienneau et al. (2013) (1.05 per 10 dB increase in noise exposure; 95% CI: 1.00-1.10).
Since 2010, a number of studies have been published that investigated the association between noise exposure and the risk of stroke (Huss et al., 2010; Sørensen et al., 2011; Hansell et al., 2013; Correia et al., 2013, Floud et al., 2013, Kluizenaar et al., 2013). Table A6 presents the core characteristics of these studies. To get an impression of the possible impact of noise on stroke, we carried out a meta-analysis on the basis of these studies.
The results of the studies are presented in Figure A6. After pooling the results of the separate studies, noise exposure was positively associated with stroke: a Relative Risk of 1.04 (95%CI: 1.00 – 1.09) per 10dB increase of the noise level was estimated. The three large cohort and ecological studies aimed at aircraft noise contribute the most to the estimate as is indicted by the weight in Figure

A6. There is some evidence of heterogeneity between studies (I^2=52%, p=0.064).

Table A6. Overview of 6 recent studies investigating the impact of noise exposure on stroke.

Study	Design	N of subjects	Noise source	Noise indicator	Endpoint(s)
Huss et al, 2010	Cohort	4.580.311	Aircraft	L_{DN}	Mortality
Sørensen et al., 2011	Cohort	57.053	Road traffic, rail traffic	L_{den}	Hospital admissions
Correia et al., 2013	Ecological	6.027.363	Aircraft	L_{DN}	Hospital admissions
Floud et al., 2013	Cross-sectional	4.861	Aircraft, road traffic	$L_{Aeq,16hr}$, L_{night}, $L_{Aeq,24hr}$	Self-reported diagnosis of stroke
Hansell et al., 2013	Ecological	3.591.719	Aircraft	$L_{Aeq,16hr}$	Mortality, hospital admissions
de Kluizenaar et al., 2013	Cohort	18.213	Road traffic	L_{den}	Hospital admissions for stroke and coronary heart disease combined

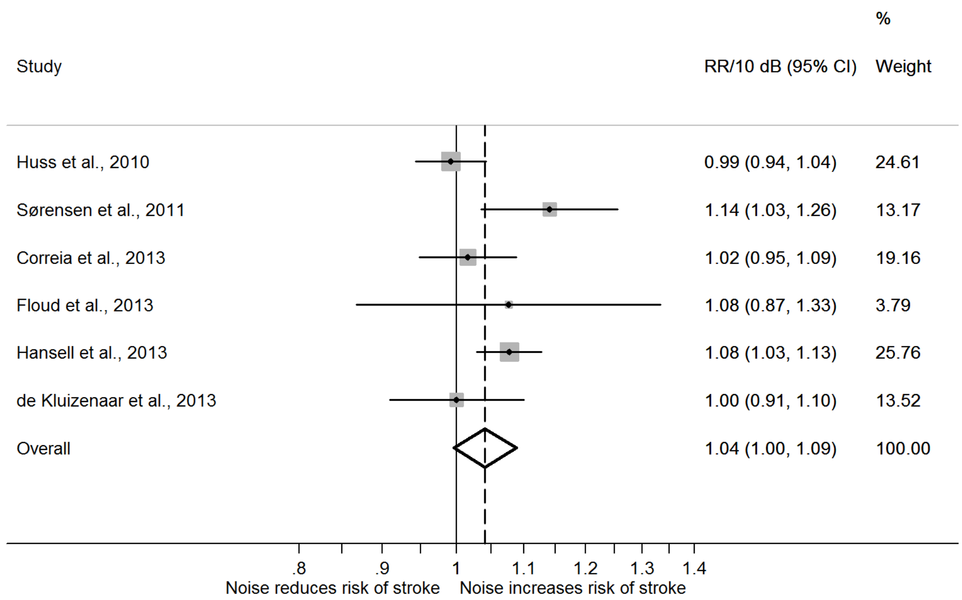

Figure A6. The association of noise with stroke endpoints. Results of 6 studies (Huss et al., 2010; Sørensen et al., 2011; Hansell et al., 2013; Correia et al., 2013, Floud et al., 2013, de Kluizenaar et al., 2013) and the overall estimate of a random effect meta-analysis

Table A7 describes the exposure-response function for mortality due to coronary heart disease and stroke; Table A8 provides the exposure-response function for the other cardiovascular endpoints (hospital admissions, the years of life lost due to disability and the years of life lost due to premature mortality). The difference is that exposure-response function for mortality is different for men and women, since the baseline incidence for both sexes are known. This is not the case for the other endpoints. Table A9 contains the base-line incidences per country for coronary heart disease; Table A10 for stroke.

Table A7. Exposure-response function for cardiovascular mortality in relation to L_{den}.

$\int_{cardio\_mortality}(L_{den})$
$(f_{male}(c)*f_{baseline}(male,c)+f_{female}(c)*f_{baseline}(female,c))*(\ln(RR_{endpoint})/10*(L_{den}\text{-Threshold}))$ if $L_{den} \geq$ Threshold $f_{male}(c)*f_{baseline}(male,c)+f_{female}(c)*f_{baseline}(female,c)$ if L_{den} <Threshold With: f_{male} and f_{female} the proportion of men and women in the total population, per country (see Annex A6) $RR_{endpoint}$=1.05 per 10 dB for coronary heart disease and $RR_{endpoint}$=1.04 per 10 dB for stroke $f_{baseline}(s,c)$: baseline incidence, sex and country dependent (see Table A8 for coronary heart disease Table A9 for stroke) Threshold=50 dB L_{den}

Table A8. Exposure-response functions for other cardiovascular endpoints (hospital admissions, years of life lost due to disability and years of life lost due to premature mortality) in relation to L_{den}.

$\int_{cardio\_other}(L_{den})$
$f_{baseline}(c)*(\ln(RR_{endpoint})/10*(L_{den}\text{-Threshold}))$ if $L_{den} \geq$ Threshold $f_{baseline}(c)$ if L_{den} <threshold With: $f_{baseline}(c)$: baseline incidence, country dependent (see Table A8 for coronary heart disease Table A9 for stroke) $RR_{endpoint}$=1.05 per 10 dB for coronary heart disease and $RR_{endpoint}$=1.04 per 10 dB for stroke Threshold=50 dB L_{den}

Figure A7 describes the probability for mortality due to coronary heart disease as function of L_{den} for each of the EEA33 countries. To keep the figure simple we plotted the additional probability; we subtracted from the probability the baseline incidence, so the country specific exposure response functions all start at 0 at 50 dB L_{den}.

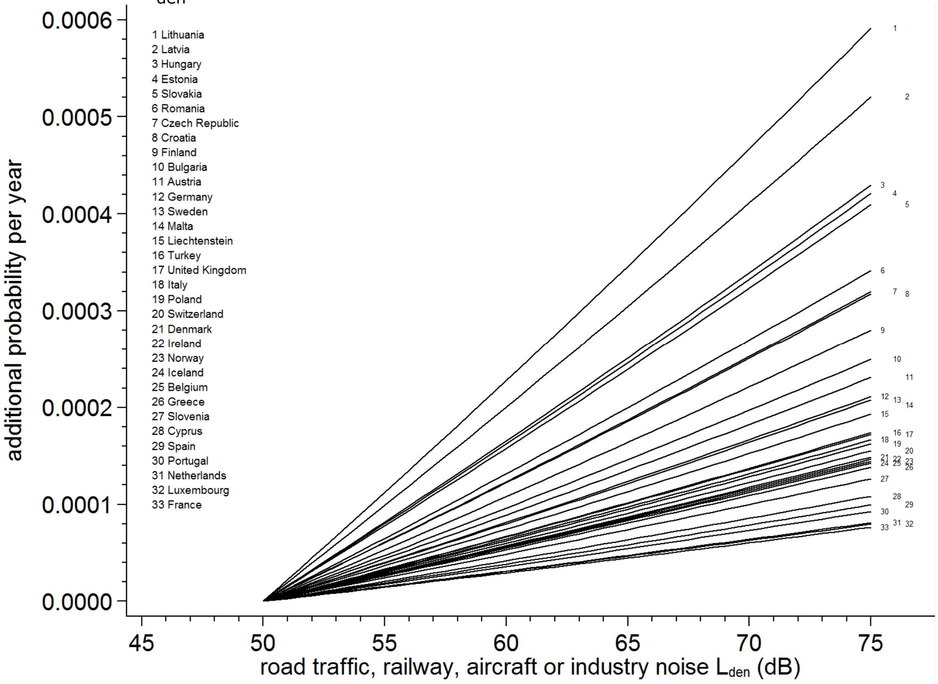

Figure A7. Additional probability per year for mortality due to coronary heart disease as function of L_{den}, by country.

Table A9 contains the base-line incidences per country for coronary heart disease; Table A10 for stroke. We used (crude) country-specific incidence data on hospital discharges and mortality from the European Cardiovascular Disease Statistics (Nichols et al., 2012; Nichols et al., 2013) to assess the 'base-line' risks for coronary heart disease and stroke. Missing country data was estimated: data for Turkey was extracted from Dinç et al. (2013); for Liechtenstein we used the mean incidence data of Austria and Switzerland; for Croatia we used available data from Slovenia, one of its neighbours. Information about the disease burden associated with coronary heart disease and stroke (years lived with disability and years life lost) was obtained from the latest WHO Global Health Estimates for 2000-2011 for the Worldbank/WHO regions "high-income countries" and "European Region (low- and middle-income countries)" (see Appendix 6 for the classifications of the EEA33 countries).

Table A9. Crude incidence of coronary heart disease mortality and of coronary heart events (both per year) and years lived with disability (YLD) and years life lost (YLL) (both per person per year) due to coronary heart disease per country

Country	Mortality/yr		Morbidity/yr	YLD/pp yr	YLL/pp yr
	Females	Males			
Austria	0.001803	0.001758	0.00954	0.00224	0.01975
Belgium	0.000955	0.001244	0.00632	0.00224	0.01975
Bulgaria	0.001654	0.002211	0.01273	0.00247	0.07641
Switzerland	0.001143	0.001252	0.00498	0.00224	0.01975
Cyprus	0.000520	0.001170	0.00198	0.00224	0.01975
Czech Republic	0.002570	0.002361	0.00771	0.00224	0.01975
Germany	0.001577	0.001681	0.00916	0.00224	0.01975
Denmark	0.001085	0.001210	0.00695	0.00224	0.01975
Estonia	0.003435	0.003029	0.00900	0.00224	0.01975
Greece	0.000784	0.001358	0.00970	0.00224	0.01975
Spain	0.000653	0.000886	0.00302	0.00224	0.01975
Finland	0.002025	0.002301	0.00791	0.00224	0.01975
France	0.000490	0.000693	0.00497	0.00224	0.01975
Croatia	0.002536	0.002353	0.00490	0.00224	0.01975
Hungary	0.003344	0.003275	0.00808	0.00224	0.01975
Ireland	0.000969	0.001293	0.00354	0.00224	0.01975
Iceland	0.000927	0.001267	0.00571	0.00224	0.01975
Italy	0.001231	0.001340	0.00529	0.00224	0.01975
Liechtenstein	0.001473	0.001505	0.00726	0.00224	0.01975
Lithuania	0.004703	0.004389	0.01312	0.00247	0.07641
Luxembourg	0.000463	0.000765	0.00606	0.00224	0.01975
Latvia	0.003937	0.004102	0.01189	0.00247	0.07641
Malta	0.001571	0.001546	0.00351	0.00224	0.01975
Netherlands	0.000522	0.000730	0.00526	0.00224	0.01975
Norway	0.001048	0.001179	0.00899	0.00224	0.01975
Poland	0.001134	0.001379	0.00884	0.00224	0.01975
Portugal	0.000656	0.000780	0.00339	0.00224	0.01975
Romania	0.002519	0.002753	0.00374	0.00247	0.07641
Sweden	0.001446	0.001757	0.00745	0.00224	0.01975
Slovenia	0.000901	0.001050	0.00411	0.00224	0.01975
Slovakia	0.003361	0.002944	0.00780	0.00224	0.01975
Turkey	0.001300	0.001380	0.00524	0.00247	0.07641
United Kingdom	0.001116	0.001549	0.00421	0.00224	0.01975

Table A10. Crude incidence of stroke events and stroke mortality (both per year) and years lived with disability (YLD) and years life lost (YLL) (both per person per year) due to stroke per country.

Country	Mortality/yr		Morbidity/yr	YLD/pp yr	YLL/pp yr
	Females	Males			
Austria	0.000761	0.000457	0.00549	0.00173	0.01031
Belgium	0.000882	0.000599	0.00358	0.00173	0.01031
Bulgaria	0.003144	0.002838	0.00613	0.00081	0.03918
Switzerland	0.000660	0.000428	0.00220	0.00173	0.01031
Cyprus	0.000528	0.000403	0.00120	0.00173	0.01031
Czech Republic	0.001386	0.000940	0.00550	0.00173	0.01031
Germany	0.000911	0.000588	0.00526	0.00173	0.01031
Denmark	0.000970	0.000732	0.00358	0.00173	0.01031
Estonia	0.001193	0.000860	0.00714	0.00173	0.01031
Greece	0.001553	0.001211	0.00464	0.00173	0.01031
Spain	0.000766	0.000576	0.00223	0.00173	0.01031
Finland	0.000965	0.000671	0.00550	0.00173	0.01031
France	0.000567	0.000434	0.00229	0.00173	0.01031
Croatia	0.002087	0.001574	0.00410	0.00173	0.01031
Hungary	0.001501	0.001312	0.01053	0.00173	0.01031
Ireland	0.000545	0.000386	0.00168	0.00173	0.01031
Iceland	0.000533	0.000466	0.00149	0.00173	0.01031
Italy	0.001262	0.000889	0.00446	0.00173	0.01031
Liechtenstein	0.000710	0.000442	0.00384	0.00173	0.01031
Lithuania	0.002158	0.001438	0.00859	0.00081	0.03918
Luxembourg	0.000762	0.000595	0.00168	0.00173	0.01031
Latvia	0.002513	0.001753	0.00692	0.00081	0.03918
Malta	0.000773	0.000499	0.00107	0.00173	0.01031
Netherlands	0.000641	0.000421	0.00229	0.00173	0.01031
Norway	0.000808	0.000571	0.00309	0.00173	0.01031
Poland	0.001037	0.000864	0.00388	0.00173	0.01031
Portugal	0.001482	0.001210	0.00310	0.00173	0.01031
Romania	0.002570	0.002292	0.00587	0.00081	0.03918
Sweden	0.000954	0.000666	0.00397	0.00173	0.01031
Slovenia	0.001256	0.000859	0.00232	0.00173	0.01031
Slovakia	0.001201	0.001015	0.00462	0.00173	0.01031
Turkey	0.000720	0.000600	0.00100	0.00081	0.03918
United Kingdom	0.000961	0.000628	0.00223	0.00173	0.01031

The number of cases of premature mortality per year due to coronary heart disease or due to stroke per country can be calculated per dB L_{den} with the following equation:

$$n_{cardio\_mortality}(L_{den},c) = n_{inhab}(L_{den}) * \int_{cardio\_mortality}(L_{den},c)$$

with:

$n_{cardio\_mortality}(L_{den},c)$	number of residents that died per year due to coronary heart disease or due to stroke per dB L_{den} per country
$n_{inhab}(L_{den},c)$	number of inhabitants per dB L_{den} per country
$\int_{cardio\_mortality}(L_{den},c)$	exposure-response equations for mortality due to coronary heart disease or due to stroke (see Table A6)

The number of hospital admission per year due to coronary heart disease or due to stroke per country can be calculated per dB L_{den} with the following equation:

$$n_{cardio\_hospital}(L_{den},c) = n_{inhab}(L_{den}) * \int_{cardio\_other}(L_{den},c)$$

with:

$n_{cardio\_hospital}(L_{den},c)$	number of hospital admission per year due to coronary heart disease or due to stroke per dB L_{den} per country
$n_{inhab}(L_{den},c)$	number of inhabitants per dB L_{den} per country
$\int_{cardio\_other}(L_{den},c)$	exposure-response equations for morbidity due to coronary heart disease or due to stroke (see Table A6)

The years of life lost due to disability (YLD) per year due to coronary heart disease or due to stroke per country can be calculated per dB L_{den} with the following equation:

$$n_{cardio\_yld}\ (L_{den}, c) = n_{inhab}(L_{den}) * \int_{cardio\_other}(L_{den}, c)$$

with:

$n_{cardio\_yld}(L_{den}, c)$	years of life lost due to disability per year due to coronary heart disease or due to stroke per dB L_{den} per country
$n_{inhab}(L_{den}, c)$	number of inhabitants per dB L_{den} per country
$\int_{cardio\_other}(L_{den}, c)$	exposure-response equations for years of life lost due to disability due to coronary heart disease or due to stroke (see Table A6)

The years of life lost due to premature mortality (YLL) per year due to coronary heart disease or due to stroke per country can be calculated per dB L_{den} with the following equation:

$$n_{cardio\_yll}\ (L_{den}, c) = n_{inhab}(L_{den}) * \int_{cardio\_other}(L_{den}, c)$$

with:

$n_{cardio\_yll}(L_{den}, c)$	years of life lost due to premature mortality per year due to coronary heart disease or due to stroke per dB L_{den} per country
$n_{inhab}(L_{den}, c)$	number of inhabitants per dB L_{den} per country
$\int_{cardio\_other}(L_{den}, c)$	exposure-response equations for years of life lost due to premature mortality due to coronary heart disease or due to stroke (see Table A6)

The total number of mortality, hospital admissions, YLD or YLL (for coronary heart disease or stroke) per country is:

$$N_{cardio\_endpoint,noise}(c) = \sum_{Lden=55}^{75} n_{cardio\_endpoint}\ (L_{den}, c)$$

In the case of absence of noise, the expected burden of mortality or morbidity is per country:

$$N_{cardio\_endpoint,no\ noise}(c) = \sum_{Lden=55}^{75} n_{inhab}\ (L_{den}, c) * f_{baseline}$$

For mortality, the baseline incidence per country is the population weighted mean baseline incidence of men and women (see Table A7). For the other endpoints, the baseline incidence can be found in Table A9 (coronary heart disease) and in Table A10 (stroke).

The attributable percentage per country is:

$$\frac{100 * (N_{cardio\_endpoint,noise}(c) - N_{cardio\_endpoint,no\ noise}(c))}{N_{cardio\_endpoint,noise}(c)}$$

The attributable percentage over the EEA33 (33 countries) is the number of cases associated with noise exposure as percentage of the total number of cases:

$$\frac{100 * (\sum_{c=1}^{33} N_{cardio\_endpoint,noise}\ (c) - \sum_{c=1}^{33} N_{cardio\_endpoint,no\ noise}\ (c))}{\sum_{c=1}^{33} N\ cardio\_endpoint, noise(c)}$$

Since the noise mapping in the framework of the END is reported between 55 and 75 dB L_{den}, the summation and the attributable percentage is restricted to the population living at levels equal to or above 55 dB L_{den}.

Annex 6: Demographical data per country

country	Economy according to World bank (1993)[a)]	World bank/WHO region (2013)[b)]	Fraction of the total population			
			females	males	adults	7-17 year olds
Austria	1	1	0.51260	0.48740	0.82052	0.10194
Belgium	1	1	0.50862	0.49138	0.79615	0.11081
Bulgaria	2	2	0.51322	0.48678	0.83876	0.08621
Croatia	2	1	0.51770	0.48230	0.81451	0.10485
Cyprus	3	1	0.51394	0.48607	0.79429	0.11338
Czech Republic	2	1	0.50900	0.49100	0.82517	0.08819
Denmark	1	1	0.50421	0.49579	0.78456	0.12145
Estonia	2	1	0.53356	0.46644	0.81598	0.09358
Finland	1	1	0.50890	0.49110	0.79972	0.10984
France	1	1	0.51574	0.48426	0.77795	0.12351
Germany	1	1	0.50874	0.49126	0.83848	0.09337
Greece	1	1	0.51004	0.48996	0.82400	0.09638
Hungary	2	1	0.52429	0.47570	0.82039	0.10023
Iceland	1	1	0.49820	0.50180	0.75013	0.13442
Ireland	1	1	0.50471	0.49529	0.74691	0.13280
Italy	1	1	0.51634	0.48366	0.83167	0.09371
Latvia	2	2	0.54284	0.45716	0.82808	0.09013
Liechtenstein	1	1	0.50536	0.49464	0.80713	0.11021
Lithuania	2	2	0.53939	0.46061	0.81480	0.10468
Luxembourg	1	1	0.50116	0.49884	0.79219	0.11685
Malta	3	1	0.50258	0.49742	0.81624	0.10491
Netherlands	1	1	0.50492	0.49508	0.79159	0.11916
Norway	1	1	0.49881	0.50119	0.77572	0.12456
Poland	2	1	0.51595	0.48405	0.81456	0.10002
Portugal	1	1	0.52284	0.47716	0.81957	0.10401
Romania	2	2	0.51500	0.48500	0.81634	0.10083
Slovakia	2	1	0.51303	0.48697	0.81148	0.10271
Slovenia	2	1	0.50536	0.49464	0.82813	0.09030
Spain	1	1	0.50662	0.49338	0.82149	0.09535
Sweden	1	1	0.50154	0.49846	0.79761	0.10693
Switzerland	1	1	0.50692	0.49308	0.81682	0.10257
Turkey	3	2	0.49771	0.50229	0.69609	0.17046
United Kingdom	1	1	0.50853	0.49147	0.78762	0.11411

[a)] 1 established market economies, 2 former socialist economies, 3 Middle eastern crescent
[b)] 1 high-income countries, 2 European Region (low- and middle-income countries)

Females

Country	Fraction of the total population according to age group (years)					
	20-29	30-39	40-49	50-59	60-69	≥70
Austria	0.06380	0.06579	0.08182	0.06908	0.05488	0.07802
Belgium	0.06278	0.06533	0.07173	0.06806	0.05412	0.07521
Bulgaria	0.06372	0.07062	0.06719	0.07214	0.07214	0.07874
Croatia	0.06245	0.06677	0.06906	0.07540	0.06040	0.08227
Cyprus	0.08547	0.08206	0.07153	0.06214	0.04866	0.04839
Czech Republic	0.06453	0.08160	0.06617	0.06695	0.06796	0.06528
Denmark	0.05867	0.06408	0.07214	0.06450	0.06270	0.06453
Estonia	0.07036	0.06738	0.06801	0.07377	0.06186	0.09164
Finland	0.06119	0.05950	0.06527	0.07029	0.06589	0.07652
France	0.06107	0.06458	0.07029	0.06705	0.05641	0.07603
Germany	0.05949	0.05862	0.08073	0.07299	0.05609	0.09209
Greece	0.05943	0.07404	0.07452	0.06612	0.05638	0.08346
Hungary	0.06101	0.07856	0.06655	0.07578	0.06668	0.07628
Iceland	0.07146	0.06813	0.06628	0.06264	0.04477	0.04809
Ireland	0.07079	0.08338	0.06988	0.05731	0.04350	0.04491
Italy	0.05297	0.07037	0.08105	0.06814	0.06002	0.09229
Latvia	0.07109	0.06633	0.07212	0.07662	0.06507	0.09557
Liechtenstein	0.06062	0.06728	0.08573	0.07575	0.05552	0.05395
Lithuania	0.06634	0.06356	0.07610	0.07647	0.06123	0.09093
Luxembourg	0.06449	0.07581	0.07940	0.06462	0.04462	0.05947
Malta	0.06938	0.06849	0.06162	0.07150	0.06685	0.06263
Netherlands	0.06102	0.06222	0.07665	0.06913	0.05829	0.06392
Norway	0.06420	0.06616	0.07058	0.06185	0.05355	0.06059
Poland	0.07672	0.07686	0.06225	0.07699	0.05575	0.06447
Portugal	0.05781	0.07683	0.07604	0.06985	0.06039	0.08311
Romania	0.06412	0.07597	0.07248	0.07249	0.05838	0.07158
Slovakia	0.07527	0.08083	0.06724	0.07282	0.05572	0.05616
Slovenia	0.06179	0.07199	0.07248	0.07317	0.05644	0.07633
Spain	0.05872	0.08269	0.07841	0.06419	0.05170	0.07481
Sweden	0.06403	0.06263	0.06784	0.06062	0.06231	0.07253
Switzerland	0.06324	0.06884	0.08026	0.06750	0.05577	0.07078
Turkey	0.08226	0.08037	0.06317	0.04846	0.03114	0.02812
United Kingdom	0.06771	0.06557	0.07387	0.06232	0.05578	0.06710

Males

Country	Fraction of the total population according to age group (years)					
	20-29	30-39	40-49	50-59	60-69	≥70
Austria	0.06494	0.06556	0.08270	0.06776	0.04995	0.05203
Belgium	0.06350	0.06683	0.07386	0.06794	0.05143	0.05121
Bulgaria	0.06818	0.07561	0.07019	0.06906	0.05922	0.05059
Croatia	0.06499	0.06885	0.06867	0.07305	0.05135	0.04881
Cyprus	0.08506	0.07093	0.06302	0.06034	0.04632	0.03894
Czech Republic	0.06803	0.08644	0.06944	0.06587	0.05948	0.04003
Denmark	0.06025	0.06423	0.07386	0.06479	0.06108	0.04804
Estonia	0.07473	0.07062	0.06631	0.06336	0.04409	0.04092
Finland	0.06439	0.06290	0.06706	0.06957	0.06220	0.04992
France	0.06067	0.06327	0.06857	0.06356	0.05207	0.05004
Germany	0.06209	0.06024	0.08423	0.07331	0.05312	0.06481
Greece	0.06324	0.07660	0.07275	0.06202	0.05139	0.06344
Hungary	0.06395	0.08055	0.06645	0.06809	0.05197	0.03987
Iceland	0.07402	0.07069	0.06597	0.06386	0.04553	0.03859
Ireland	0.06734	0.08132	0.06999	0.05694	0.04344	0.03474
Italy	0.05426	0.07020	0.07965	0.06463	0.05501	0.06324
Latvia	0.07449	0.06632	0.06681	0.06371	0.04369	0.04122
Liechtenstein	0.06322	0.06706	0.08480	0.07345	0.05768	0.03836
Lithuania	0.06919	0.06174	0.07024	0.06459	0.04212	0.04246
Luxembourg	0.06655	0.07584	0.08448	0.06752	0.04484	0.04081
Malta	0.07370	0.07276	0.06338	0.07168	0.06398	0.04389
Netherlands	0.06216	0.06217	0.07791	0.06960	0.05794	0.04620
Norway	0.06673	0.06966	0.07483	0.06414	0.05380	0.04348
Poland	0.07935	0.07897	0.06288	0.07262	0.04626	0.03583
Portugal	0.05773	0.07309	0.07176	0.06412	0.05180	0.05527
Romania	0.06789	0.07578	0.07280	0.06767	0.04840	0.04669
Slovakia	0.07854	0.08491	0.06808	0.06922	0.04513	0.03060
Slovenia	0.06694	0.07916	0.07605	0.07577	0.05260	0.04546
Spain	0.06024	0.08734	0.08087	0.06309	0.04783	0.05197
Sweden	0.06736	0.06508	0.07011	0.06159	0.06169	0.05466
Switzerland	0.06491	0.06953	0.08159	0.06852	0.05339	0.04917
Turkey	0.08543	0.08194	0.06472	0.04853	0.02821	0.02036
United Kingdom	0.06824	0.06503	0.07204	0.06102	0.05321	0.05008

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