Eionet Report - ETC/ACM 2018/10

Implications of environmental noise on health and wellbeing in Europe

Based on data from the second (2012) and third (2017) round of noise assessment in the framework of the European Noise Directive

February 2019

Authors:
Danny Houthuijs, Wim Swart, Elise van Kempen

ETC/ACM consortium partners: National Institute for Public Health and the Environment (RIVM), Aether, Czech Hydrometeorological Institute (CHMI), Institute of Environmental Assessment and Water Research (CSIC/IDAEA), EMISIA, Institut National de l'Environnement Industriel et des Risques (INERIS), Norwegian Institute for Air Research (NILU), Öko-Institute, Öko-Recherche, Netherlands Environmental Assessment Agency (PBL), Universitat Autónoma de Barcalona (UAB), Umweltbundesamt Wien (UBA-V), Vlaamse Instelling voor Technologisch Onderzoek (VITO), 4sfera Innova

European Environment Agency
European Topic Centre on Air Pollution and Climate Change Mitigation

Cover photo – Residential area with sound barrier along a nearby road (copyright free)

Authors
Danny Houthuijs, Wim Swart and Elise van Kempen: National Institute for Public Health and the Environment (RIVM, NL)

European Topic Centre on Air Pollution
and Climate Change Mitigation
PO Box 1
3720 BA Bilthoven
The Netherlands
Tel.: +31 30 274 8562
Fax: +31 30 274 4433
Web: http://acm.eionet.europa.eu
Email: etcacm@rivm.nl

Contents

Acknowledgements

We would like to thank Maria José Ramos and Núria Blanes Guàrdia, Universitat Autònoma de Barcelona, Barcelona (Spain) for providing the reported data and for the imputation of the not (yet) reported data. We also thank Eulalia Peris and Martin Adams (European Environmental Agency, Kopenhagen, Denmark) for their guidance during the study.

1 Introduction

In 2014 the European Environment Agency's (EEA) published its first noise assessment report with an overview and analysis of environmental noise based upon information reported to EEA by its member countries following the requirements of the EU Directive 2002/49/EC relating to the assessment and management of environmental noise (the Environmental Noise Directive: END; EU, 2002). In this EEA report findings were presented of a health impact assessment describing the health implications associated with environmental noise exposure in Europe. The methodology of the health impact assessment was mainly based on the 2011 WHO report on the burden of disease and noise (WHO, 2011) supplemented with more recent evidence on the effects of noise on cardiovascular disease (Houthuijs et al., 2014).

Recently the WHO Regional Office for Europe released Environmental Noise Guidelines for the European Region (WHO, 2018). The main purpose of these guidelines is to provide recommendations for protecting human health from exposure to environmental noise from various sources. Also in 2018, a guidance document was published to assess and evaluate the (cumulative) health effects at population level due to environmental noise exposure to complement the noise mapping (van Kamp et al. 2018). This project was commissioned by the European Commission to give authorities in the European Union Member States guidance how to estimate health and well-being effects and used them on a local level to justify or establish priorities within the Noise Action Plans.

The health impact assessment in the Noise in Europe report of the EEA (2014) was based on data of the second round of noise mapping. The completeness of the data varied at that time between 44 and 63%, depending on the noise source. This implies that the burden of disease was underestimated in the report. Since that time the completeness of the dataset of the second round has increased and results of the third round of noise mapping (reporting deadline 30 December 2017) have become available.

The EEA requested an update of the health impact assessment of environmental noise given the recent launch of the WHO Environmental Noise Guidelines for the European Region and the availability of more complete noise data.
The objectives of this study are:

- To carry out an health impact assessment for environmental noise for the EEA member countries based on the data of the second and third round of noise mapping in the framework of the END and using updated exposure-response curves;
- To provide key results for various health endpoints;
- To carry out additional analyses to evaluate the effects of changes in the methodology and to assess the sensitivity of the results for choices in the assessment;
- To document the details of the applied methodology for future assessments.

The methodology of the health impact assessment is described in Chapter 2. The key findings of the main and additional analyses are reported in Chapter 3. The results are discussed in Chapter 4. The conclusions are formulated in Chapter 5.

2 Methods

In a health impact assessment four steps can be distinguished:

1. Selection of the health endpoints
2. Assessment of the population exposure
3. Selection of the exposure-response relations
4. Estimation of the number of (additional or attributable) cases

In this chapter we describe the methodology that we applied and the input data that was used in each of the four steps. We will carry out analyses in addition to the estimation of the number of cases of various health effects that can be attributed to environmental noise. These additional analyses are introduced in section 2.5.

The Environmental Noise Guidelines for the European Region (WHO, 2018) and the guidance document (van Kamp et al., 2018) are important ingredients for this chapter. The reports have different scopes and therefore we first describe our view on how the reports relate to each other.

The Environmental Noise Guidelines for the European Region and the guidance document are both about the health risk assessment of environmental noise. The main focus of the WHO Environmental Noise Guidelines is the so-called health hazard characterisation while the focus of the guidance document is the health impact assessment of environmental noise. Health hazard characterisation involves, in this specific case, the identification of the hazards of environmental noise by the collection, evaluation, and interpretation of the available evidence from social surveys and epidemiological and other studies concerning the association between environmental noise and (selected) health outcomes. It comprises the hazard identification and the exposure response assessment. Health impact assessment involves the quantification of the expected health burden due to environmental noise exposure in a specific population. It combines exposure assessment, exposure-response assessment and risk characterisation. Elements of health hazard characterisation and health impact assessment overlap and are interconnected, but health hazard characterisation can also be viewed as a condition for health impact assessments. It provides the justification for them and can provide data for the calculation of risk estimates (WHO, 2000).

2.1 Selection of the health endpoints

The selection of the health endpoints was already extensively covered in the Environmental Noise Guidelines for the European Region (WHO, 2018) and in the guidance document (van Kamp et al., 2018). In this section, we summarise the process of selection of health endpoints in both report. Subsequently we describe the selected endpoints for the health impact assessment for the EEA member countries in this report.

The Guideline Development Group (GDG) was responsible for the recommendations of environmental noise guidelines for the European Region (WHO, 2018). The guidelines are noise source specific. Outdoor exposure to environmental noise from road traffic, railway traffic, aircraft, wind turbines as well as outdoor and indoor exposure during leisure activities were the focus of the work. Environmental industrial noise was not specifically considered mainly due to the large heterogeneity and specific features of this noise source, and due to its localised character.

The GDG first identified key health outcomes associated with environmental noise and subsequently rated the relevance of these health outcomes based on the seriousness and prevalence of the outcomes and the anticipated availability of evidence for an association with noise exposure. The GDG selected cardiovascular disease, annoyance, effects on sleep, cognitive impairment and hearing impairment and tinnitus as critical health outcomes. Adverse birth outcomes, quality of life, well-being and mental health and metabolic outcomes were identified as important health outcomes. A team of key experts, the

Systematic Review Team, was subsequently responsible for the systematic literature and evidence reviews for these critical and important health outcomes.
To derive guideline exposure levels, the GDG further prioritised within the list of critical health outcomes. The prioritisation was based on the impact of the disease and the disability weights for the health outcomes. The prioritised health outcomes were the incidence of ischaemic heart disease (IHD); hypertension, highly sleep-disturbed; highly annoyed; reading and oral comprehension; and permanent hearing impairment. The evidence for health risks of these prioritised critical health endpoints had the largest influence on the recommendations in the Environmental Noise Guidelines for the European Region. Only source specific exposure–response functions were used for the derivation of the guidelines exposure levels, because of the differences in the characteristics of noise sources.

In the WHO Environmental Noise Guidelines report a section is devoted to the methodological guidance for health risk assessment of environmental noise as part of a chapter on the implementation of the environmental noise guidelines. The text in the section speaks of health risk assessment, but the content is about health impact assessment. The report states that "The scientific evidence reviewed and summarized in these guidelines implies that the following health outcomes can be quantified in a health risk (sic) assessment, ..". We have listed the health outcomes in Table 2-1 and added in brackets the quality of the evidence as described in the WHO report.

Table 2-1 **Recommend health endpoints for health impact assessment and the quality of the evidence for various environmental noise sources (WHO, 2018)**

Noise source	Recommended health endpoints (and quality of the evidence)	
	Can be quantified	Potentially
Road traffic	Incidence of IHD (high quality), annoyance (moderate quality) and sleep disturbance (moderate quality)	Incidence of stroke (moderate quality, single study) and diabetes (moderate quality, single study)
Railway	Annoyance and sleep disturbance (both moderate quality)	
Aircraft	Annoyance, reading and oral comprehension in children and sleep disturbance (all moderate quality)	Change in waist circumference (moderate quality, single study) and incidence of IHD (very low quality)
Wind turbine	Annoyance (low quality, conditional guideline level)	
Industry	Not included in the Environmental Noise Guidelines for the European Region	

WHO makes a distinction between "can be quantified" and "potentially" without a further elucidation of the term "potentially". The recommended heath endpoints that can be quantified all belong to the priority measures of the list of health outcomes that WHO considers as critical. From the health outcomes in the last column of Table 2-1, stroke was also on the list of critical health outcomes but not seen as a priority outcome. Diabetes and change in waist circumference belong to the metabolic endpoints of the list of health outcomes that WHO labels as important.

The guidance document describes among others the steps for a health impact assessment with data collected in the framework of the END (van Kamp et al., 2018). The selection of the health endpoints in this document is based on the reviews carried out by the Systematic Review Team for the WHO environmental noise guidelines for the European Region (Basner and McGuire, 2017; Brown and van Kamp, 2017; Guski et al., 2017; Nieuwenhuijsen et al., 2017; Śliwińska-Kowalska and Zaborowski, 2017; Clark and Paunovic, 2018; van Kempen et al., 2018). The selected endpoints are described in Table 2-2. In the guidance document the description coronary heart disease (CHD) is used instead of the description ischaemic heart disease (IHD); these descriptions are exchangeable. We will use the description IHD in this report.

Table 2-2 **Health endpoints selected for inclusion in a health impact assessment in the framework of the END (van Kamp et al, 2018)**

Health endpoint	Noise source in END	Population at risk
Highly sleep disturbed	all sources	adults
Highly annoyed	all sources	adults
Reading impairment	aircraft	children
Incidence of IHD	all sources	adults
Premature mortality due to IHD	all sources	adults

There is a considerable overlap between the health endpoints in the Tables 2-1 and 2-2. Table 2-2 does not include the health endpoints stroke, change in waist circumference and diabetes that are mentioned in Table 2-1 and has as additional endpoint premature mortality due to IHD. Change in waist circumference was not considered as health outcome, since it was regarded as risk factor. The available evidence for diabetes was based on a limited number of studies. Stroke was selected as a-priori health endpoint in the guidance document. The number of studies on stroke is much lower than for IHD and only carried out for road traffic and aircraft noise. The associations between the noise from these sources and the incidence of stroke were only partly confirmed for mortality due to stroke. Since there was only one single study on the incidence with moderate quality, there were concerns about the transferability and generalisation of this relation for use in a health impact assessment. So, in the final selection stroke was not included. The risk for IHD was extended with mortality, since the biological mechanism is the same for incidence and mortality and there are only small differences in relative risks between incidence and mortality studies.

In Table 2-1 the selection of the health endpoint is more noise source dependant than Table 2-2 where all health endpoints, except reading impairment, are linked to the four END noise sources. The WHO report focussed on the health risk of specific sources to derive guideline exposure levels for each of these sources. It is not necessary in this process to take into account all selected critical and important health endpoints. The aim of the END is among others to reduce on a prioritised basis the health effects of environmental noise. For the process of prioritising, it is essential that the different noise sources are treated in a similar way in a health impact assessment. Therefore, it was considered in the guidance document whether it is appropriate to use information on the risk of exposure to noise from other sources in the case that studies on the risks of the specific noise source are limited or lacking. It was concluded that this was appropriate for the selected health endpoints in Table 2-2, except reading impairment.

In view of the above considerations, we followed in this report the selection of health endpoints made in the guidance document: highly sleep disturbed, highly annoyed, reading impairment, incidence and premature mortality due to IHD. In the Noise in Europe 2014 the same five health endpoints were quantified as well as hypertension and stroke. The results of stroke were based at that time on an ad-hoc meta-analysis. At that time, the quality of the studies was not weighted so the incorporation of stroke can be considered as premature. Hypertension was not selected in the guidance document since it was considered as risk factor and not as health outcome. Also, it was concluded that hypertension was sufficiently covered by the incorporation of IHD.

2.2 Assessment of the population noise exposure

2.2.1 Population noise exposure data

The population noise exposure data of the second and third round of noise mapping used in this report is based on 32 countries (EU28, Iceland, Liechtenstein, Norway and Switzerland; Turkey did not provide information). The data used for this report includes the most recent updates/late deliveries up to 20th of

May 2018 with some updates to 12th of September 2018. The datasets contain population noise exposure distributions for seven combinations of assessment areas (major roads and major sources) and noise sources (road traffic, railway, aircraft and industry), obtained using noise modelling and measurement methods, and reported to the EEA. We refer in the report to the 2012 dataset for the second round and to the 2017 dataset for the third round of noise mapping.

Given the gaps in the reported data, imputation of data was carried out to be able to estimate the potential dimension of environmental noise in Europe. This "gap filling" methodology is based on modelling the relation between reference information (e.g. total population or total length of transport networks) and the reported exposed population. If there was no statistical relation, country averages or European averages were used for the imputation.

The reported and the gap filled datasets contain the population per 5 dB exposure category. For the health impact assessment, it is necessary to assign an average noise exposure to each of these categories. A simple approach is using the midpoint for each noise category, for example 57.5 dB for the noise category 55 to 60 dB. This method assumes that the noise distribution within the categories is uniformly distributed, which is unlikely. We therefore estimated the average exposure per noise category by refining the 5 dB categories to a resolution of 1 dB and then calculating the average exposure. For reasons that will become clear later, we first have to estimate the population in exposure categories below the lowest assessment values of the END (55 dB L_{den} and 50 dB L_{night}). We describe in the upcoming sections how we carried out this (statistical) estimation per noise source. Subsequently, the procedure for the refinement to 1 dB is given. The estimation is carried out for the gap filled datasets. The obtained average exposures per 5 dB category are also used for the reported data.

2.2.2 Road traffic noise within agglomerations

In 2018, the full road traffic noise exposure distribution within agglomerations of EEA member states was estimated per country using a grid approach (Houthuijs et al., 2018). The exposed population below 55 dB L_{den} and 50 dB L_{night} is estimated per country by applying the following formulas, using the fractions described in the above mentioned report:

$$Population_{Lden,5\ dB\ category} = Fraction_{Lden,5\ dB\ category} * Population_{Above\ 55\ Lden}$$

$$Population_{Lnight,5\ dB\ category} = Fraction_{Lnight,5\ dB\ category} * Population_{Above\ 50\ Lnight}$$

The applied fractions per country are listed in Annex 1 (L_{den}) and in Annex 2 (L_{night}). The abbreviations used in Annex 1 and 2 for the countries are described in Annex 3. For countries, that were not included in the report of Houthuijs et al., 2018, the mean fraction per noise exposure category from the report can be used. These fractions are given in Table 2-3.

Table 2-3 Fraction from population above 55 dB L_{den} or 50 dB L_{night} to estimate the population in lower 5 dB exposure category for road traffic noise within agglomerations for countries not included in Houthuijs et al. (2018)

Exposure category	Fraction for L_{den}	Fraction for L_{night}
50 - 54 dB	0.6321346	-
45 - 49 dB	0.2771679	0.4428878
40 - 44 dB	0.0682108	0.3693296
35 – 39 dB	0.0168865	0.1476172
30 – 34 dB	0.0041742	0.0316412
25 – 29 dB	0.0014259	0.0085242

2.2.3 Road traffic noise from major roads

For the exposure to road traffic from major roads, we used findings of Alberts et al. (2016). Alberts et explored how many inhabitants in Europe are exposed to road traffic noise from major roads, making use of the 2012 END data and of additional sources of information.
The population below 55 dB L_{den} and 50 dB L_{night} is calculated by applying the following formulas:

$$Population_{Lden\ 50-54\ dB} = 0.71071 * Population_{Above\ 55\ dB\ Lden}$$

$$Population_{Lnight\ 45-49\ dB} = 0.77215 * Population_{Above\ 50\ dB\ Lnight}$$

If countries reported the population for the category 50 - 54 dB L_{den} and/or 45-49 dB L_{night}, then this reported information is used instead of the estimated population.

Subsequently the same procedure is followed for the lower noise categories. The starting point is now the total population above 50 dB L_{den} and above 45 dB L_{night} using the information from the previous step. The following formulas are applied:

$$Population_{Lden,5\ dB\ category} = Fraction_{Lden,5\ dB\ category} * Population_{Above\ 50\ Lden}$$

$$Population_{Lnight,5\ dB\ category} = Fraction_{Lnight,5\ dB\ category} * Population_{Above\ 45\ Lnight}$$

The fractions for the lower exposure categories are given in Table 2-4.

Table 2-4 Fraction from population above 50 dB L_{den} or above 45 dB L_{night} to estimate the population in lower 5 dB exposure category for road traffic noise from major roads

Exposure category	Fraction for L_{den}	Fraction for L_{night}
45 - 49 dB	0.68267	-
40 - 44 dB	1.05637	0.71071
35 – 39 dB	1.68894	1.16786
30 – 34 dB	-	1.80714
25 – 29 dB	-	2.88929

2.2.4 Railway noise

The method for railway noise from major sources and within agglomerations is identical to the procedure for road traffic noise from major roads (section 2.2.3).

2.2.5 Aircraft noise

For aircraft noise from major sources and within agglomerations, we used information from the ANOTEC study (ANOTEC, 2003). In this study, the noise exposure around 51 airports in 15 European countries was modelled for 2002. In commission of the National Institute of Public Health and the Environment, the Netherlands, the exposure modelling was extended in 2009 to lower noise levels (40 L_{den} and 30 dB L_{night}). Also, the noise model was updated (for details: see Houthuijs et al., 2015). No distinction was made between noise exposure within and outside agglomerations.

We applied the procedure described for road traffic noise from major roads, with some modifications.
In deviation from the other noise sources, we used as reference populations the number of inhabitants from 55 to 60 L_{den} and from 50 to 55 L_{night}. Restrictions in spatial planning are often in place at higher noise levels and may differ between airports, so the total population equal or above 55 dB L_{den} and equal or above 50 dB L_{night} might be less representative for the exposure at lower levels of aircraft noise. Subsequently, the population in the lower exposure categories is estimated according to:

$$Population_{Lden,5\ dB\ category} = Fraction_{Lden,5\ dB\ category} * Population_{\ 55-59\ \ dB\ Lden}$$

$$Population_{Lnight,5\ dB\ category} = Fraction_{Lnight,5\ dB\ category} * Population_{\ 50-54\ dB\ Lnight}$$

The (mean) fraction per noise category per country was extracted from the Anotec dataset. If no airports were available for a country, then the average of the full Anotec dataset was used. These average fractions for the lower exposure categories are given in Table 2-5. We do not provide the information about the fractions for individual countries in this report.

Table 2-5 Fraction from population 55-59 dB L_{den} or 50-54 dB L_{night} to estimate the population in lower 5 dB exposure category for road traffic noise from major roads

Exposure category	Fraction for L_{den}	Fraction for L_{night}
50-54 dB	2.425775	-
45-49 dB	4.400184	2.659887
40-44 dB	6.444598	6.037403
35-39 dB	-	9.275389
30-34 dB	-	15.15587

If countries reported the population for 50 - 54 dB L_{den} and/or 45-49 dB L_{night}, this reported information replaced the estimated population.

2.2.6 Industrial noise

For industry, we used data from the Netherlands Environmental Assessment Agency about the exposure to industry noise in the Dutch population (PBL, 2009). The same method is applied as is the case for road traffic noise from major roads. First, the fraction of the exposed population is calculated for the noise category 50-54 dB L_{den} and 45-49 dB L_{night}. The results are added to the number of people above 55 dB L_{den} and above 50 dB L_{night}. If countries reported the population for 50 - 54 dB L_{den} and/or 45-49 dB L_{night}, then this reported information was used instead of the estimated population. Subsequently the estimation for the lower noise categories is based on the total population above 50 dB L_{den} and above 45 dB L_{night}. The fractions used are described in Table 2-6.

Table 2-6 Fraction from population above 55 dB L_{den} or 50 dB L_{night} and above 50 dB L_{den} or 45 dB L_{night} to estimate the population in lower 5 dB exposure category for industrial noise

Exposure category	Fraction for L_{den}	Fraction for L_{night}
Based on population above 55 dB L_{den} and above 50 dB L_{night}		
50 - 54 dB	3.191736	-
45 - 49 dB	-	2.217099
Based on total population above 50 dB L_{den} and above 45 dB L_{night}		
45 - 49 dB	2.207175	-
40 - 44 dB	3.468227	3.156831
35 – 39 dB	3.634048	6.505400
30 – 34 dB	-	7.570637
25 – 29 dB	-	7.314349

2.2.7 Average exposure per 5 dB category

We transferred the 5 dB in a 1 dB exposure distribution using the methodology of Van Den Hout et al. (2011) with minor modifications.

As example, we illustrate the procedure with an exposure distribution for L_{den} that consists of ten numbers, N1-N10, the percentages of inhabitants exposed to <35, 35-39, 40-44, 45-49, 50-54, 55-59, 60-

64, 65-69, 70-74 and ≥75 dB L_{den}, respectively. The width of the intervals is 5 dB. It is assumed that the highest interval is 75 - 79 dB. It is also assumed that the lowest interval (<35 dB) consists of two 5 dB intervals (25-29 and 30-34 dB) with 75% of the population in the 30-34 dB and 25% of the population in the 25-29 dB category.

For each 5 dB interval, the mean gradient dN/dL (in % per dB) is given by:

$$(dN/dL)= 1/2 * [1/5 *(N_{j+1} - N_j)+ 1/5 * (N_j - N_{j-1})]$$

Next, the distribution is refined by replacing each 5 dB interval by five 1 dB intervals:

$$N_{j,k} = 1/5 * [N_j + (dN/dL)_j * (k-3)]$$

where index k = 1, 2, to 5 runs over the five 1 dB intervals in 5 dB interval j.
Negative percentages in the refined distribution are avoided by applying an upper limit to the gradients.

The procedure is tailored for each of the assessments, since the number of exposure categories can vary between sources, location and noise exposure indicator.
Subsequently, we calculated the average noise exposure for the 5 dB categories above 55 dB L_{den} and above 50 dB L_{night} based on the 1 dB population exposure distribution. For each 1 dB class, we used the midpoint value in this calculation.

2.3 Identification and selection of the exposure-response relations

The identification and selection of the exposure exposure-response relations is described in this section. We also provide formulas for the relations so they can be applied in other health impact assessments as well. For details about the derivation of the relations, we refer to the reviews that were carried out for the WHO Environmental Noise Guidelines for the European Region or to other literature sources.

2.3.1 Highly annoyed

The relevant exposure response relations for annoyance from road traffic, railway and aircraft noise were already identified and selected in the WHO Environmental Noise Guidelines report and in the guidance document. They are based on the evidence review of Guski et al. (2017). Results from several studies were pooled to derive the exposure response relations.

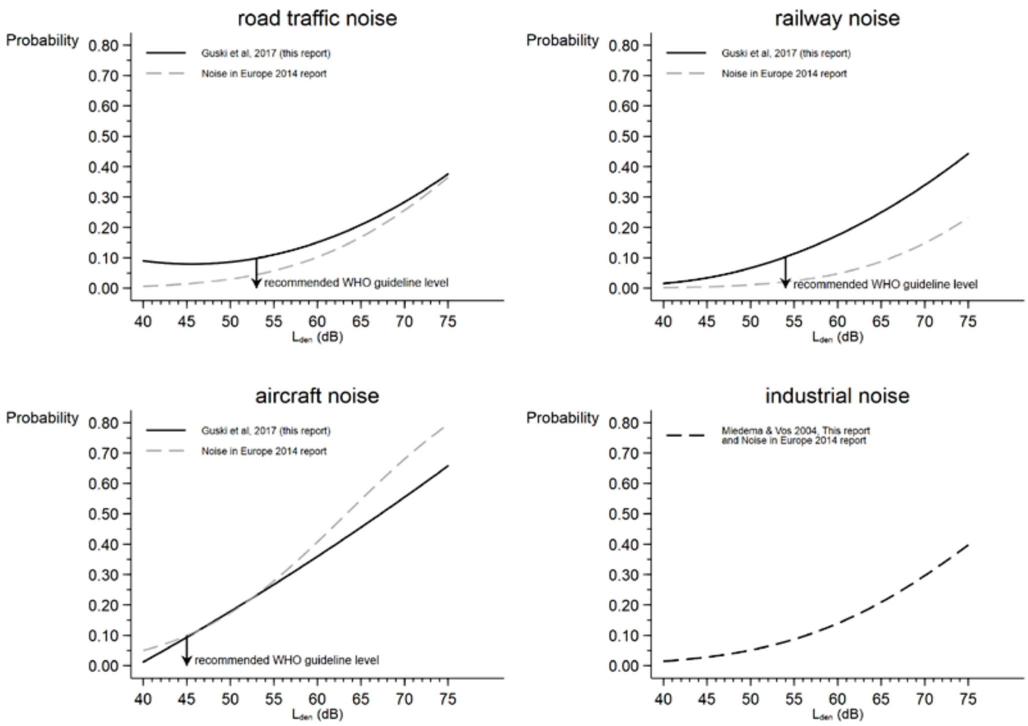
Guski et al. indicate that only one study on stationary industrial noise showed up in their systematic literature search. This study of Miedema and Vos (2004) derived three exposure-response relations based on a field study in the Netherlands at 11 locations (two shunting yards, one seasonal industry, and eight other industries). As mentioned earlier, industrial noise was not considered in the WHO Environmental Noise Guidelines. The guidance report identified the exposure response relation for other industries from Miedema and Vos (2004) without further comments. This relation is also used for this report. This relation was earlier selected for the Noise in Europe 2014 report, since it was based on eight locations (Houthuijs et al., 2014).

The formulas for the relation between the annual 24 hour noise level (L_{den}) and the probability of severe annoyance are given in Table 2-7. The relations are shown in Figure 2-1. Guski et al. calculated the relations from 40 dB L_{den} onwards up to 75-80 dB L_{den}, depending on the noise source.

Table 2-7 **Exposure-response functions for severe annoyance in relation to the annual 24 hour noise level (L_{den}) for road traffic, railway, aircraft and industry noise (Guski et al., 2017 and Miedema and Vos, 2004)**

Noise source	Exposure response function: $\int_{annoyance}(L_{den})$
Road traffic	(78.927-3.1162*L_{den}+0.0342*L_{den}^2)/100
Railway	(38.1596-2.05538*L_{den}+0.0285*L_{den}^2)/100
Aircraft	(-50.9693+1.0168*L_{den}+0.0072*L_{den}^2))/100
Industry	1-normal((72-(-126.52+(L_{den})*(2.49)))/sqrt(2054.43))

Figure 2-1 **Applied exposure response relations for the probability of severe annoyance in relation to the annual 24 hour noise level (L_{den}) for road traffic, railway, aircraft and industrial noise in this report and in the Noise in Europe 2014 report (Guski et al., 2017 and Miedema and Vos, 2004)**



In the graphs in Figure 2-1, we projected the recommended WHO guideline noise level for the specific noise source that corresponds with a 0.10 probability of being highly annoyed. Also, the exposure-response-relations that were used in the EEA Noise and Health 2014 report are plotted in the graphs. At that time, the relations in Annex III of the END were used, except for aircraft noise where an updated exposure-response relation was applied (Janssen and Vos, 2009).

2.3.2 Highly sleep disturbed

The exposure response relations for sleep disturbance from road traffic, railway and aircraft noise were also identified and selected in the WHO Environmental Noise Guidelines report and in the guidance document. The relations are described in the evidence review of Basner and McGuire (2017) as the combined estimates for the questions on difficulty falling asleep and questions on awakenings. The relations are valid for a range of 40 to 65 dB L_{night}.

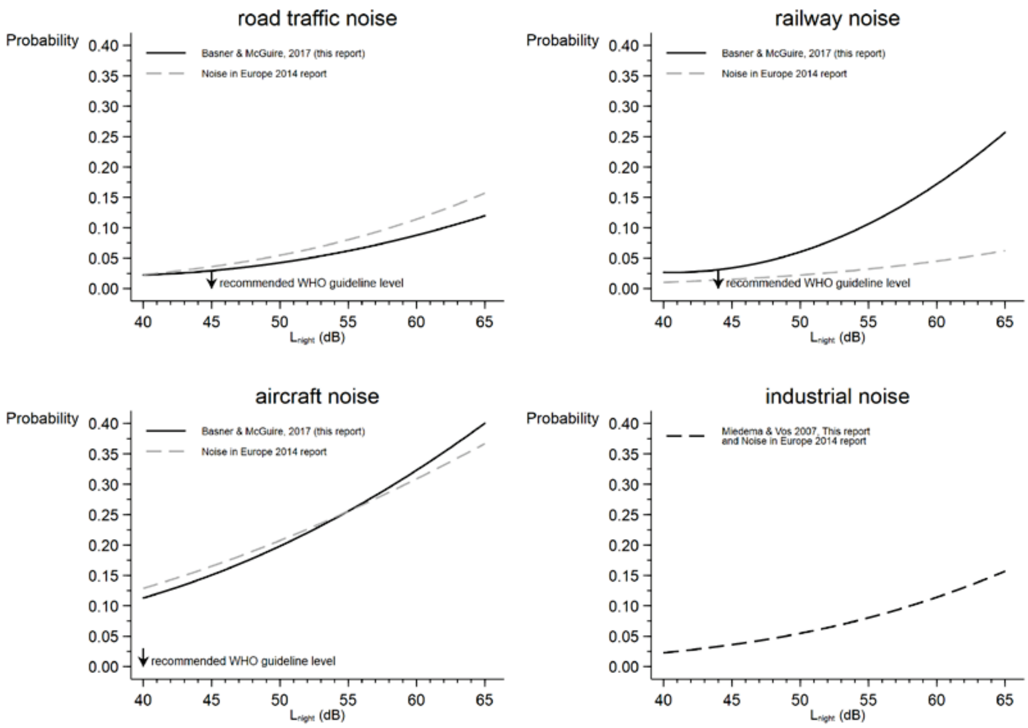
The review of Basner and McGuire does not mention industrial noise. Also sleep disturbance due to industrial noise is not discussed in the WHO Environmental Noise Guidelines report, nor in the guidance document. In the Noise in Europe 2014 report, the relation between night-time road traffic noise and self-reported sleep disturbance (Miedema and Vos, 2007) was used as an indication for the relation between night-time industry noise and self-reported sleep disturbance. The rationale for this choice was at that time that the exposure-response relations for severe annoyance for noise from road traffic and noise from industry were similar (Houthuijs et al., 2014). We use in this report the same indicative relations as in the Noise in Europe 2014 report.

The formulas for the relation between the annual night time noise level (L_{night}) and the probability of severe sleep disturbance are given in Table 2-8. The relations are shown in Figure 2-2.

Table 2-8 Exposure-response functions for severe sleep disturbed in relation to the annual night time noise level (L_{night}) for road traffic, railway, aircraft and industry noise (Barsner and McGuire, 2017 and Miedema and Vos, 2007)

Noise source	Exposure response function: $\int_{sleepdisturbance}(L_{night})$
Road traffic	(19.4312-0.9336*L_{night}+0.0126*L_{night}^2)/100
Railway	(67.5406-3.1852*L_{night}+0.0391*L_{night}^2)/100
Aircraft	(16.7885-0.9293*L_{night}+0.0198*L_{night}^2)/100
Industry (indicative)	1-normal((72-(-90.70+(L_{night})*(1.80)))/sqrt(1789+272))

Figure 2-2 Applied exposure response relations for the probability of highly sleep disturbed in relation to the annual night time noise level (L_{night}) for road traffic, railway, aircraft and industrial noise in this report and in the Noise in Europe 2014 report (Barsner and McGuire, 2017 and Miedema and Vos, 2007)



We added in the graphs the recommended WHO guideline noise level for road traffic and railway noise, that corresponds with a 0.03 probability of being highly sleep disturbed. Since no reliable exposure data was available under 40 dB L_{night}, the recommended guideline noise level for aircraft noise was set on 40 dB L_{night}, corresponding with a 0.11 probability of being highly sleep disturbed The exposure-response-relations that were applied in the Noise and Health 2014 report are also shown in the graphs. Similar to annoyance, the relations in Annex III of the END were applied, except for aircraft and industry noise.

2.3.3 Reading skills and oral comprehension

There is evidence of moderate quality that aircraft noise can delay the reading age at young age (WHO, 2018). The GDG considered a delay of one month a relevant absolute risk. This relevant risk increase was found at 55 dB L_{den}. The evidence review paper on environmental noise and cognition indicates that only one study demonstrated an exposure-response relation for aircraft noise exposure (Clark and Paunovic,

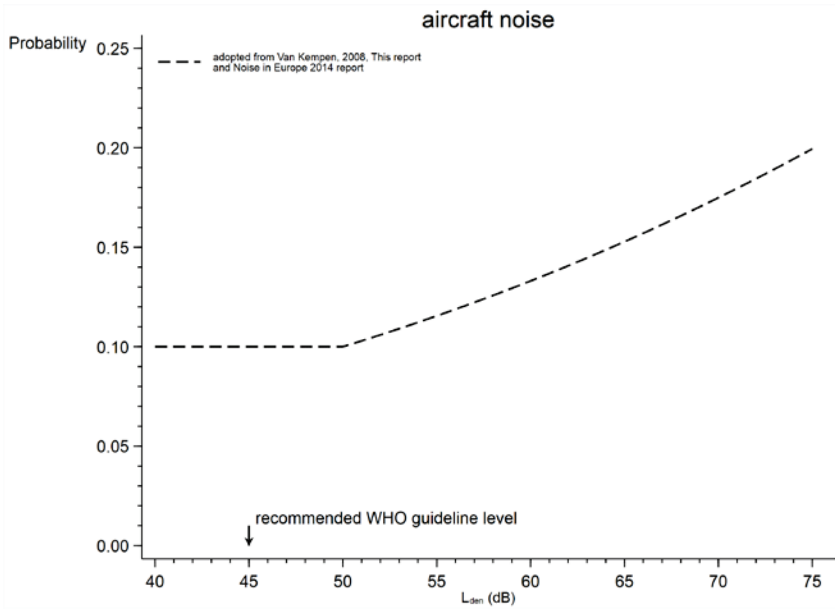
2018). In this multi-centre study in three countries a 10 dB increase in aircraft noise exposure (as $L_{16h,Aeq}$) was associated, on average, with 2-4 months delay in reading age (Clark et all, 2006). There was no clear evidence of a threshold.
This average delay per child from the RANCH study had to be transformed to a binary health endpoint (present or absent) to be of use in a health impact assessment. For the Noise in Europe 2014 report an exposure-response relation was derived using the RANCH data between L_{den} and reading impairment. 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}. An odds ratio per 10 dB of 1.38 (95%CI 1.09 – 1.75) was estimated per 10 dB increase in aircraft noise level. For details, we refer to van Kempen (2008) and Houthuijs et al. (2014). This transformation was adopted in the guidance document (van Kamp et al., 2018).

The formula for the relation between the annual 24 hour noise level (L_{den}) and the probability of reading impairment is given in Table 2-9. The relation is plotted in Figure 2-3.

Table 2-9 Exposure-response functions for reading impairment in relation to the annual 24 hour noise level (L_{den}) for aircraft noise (adopted from Clark et al., 2006 and van Kempen, 2008)

Noise source	Exposure response function: $\int_{reading}(L_{den})$
Aircraft	1/(1+exp(-(ln(0.1/0.9)+(ln(1.38)/10*(L_{den}-50))))) if L_{den}≥50 dB and 0.1 if L_{den} <50 dB

Figure 2-3 Applied exposure response relation for the probability of reading impairment in relation to the annual 24 hour noise level (L_{den}) for aircraft noise in this report and in the Noise in Europe 2014 report (adopted from Clark et al., 2006 and van Kempen, 2008)



The recommended WHO guideline noise level in Figure 2-3 corresponds with a 0.10 probability of being highly annoyed; reading skills and oral comprehension were not the most critical endpoints for the derivation of a guideline noise level for aircraft noise.

2.3.4 Ischaemic heart disease

In the systematic review on environmental noise and cardiovascular and metabolic effects, the most comprehensive evidence was available for road traffic noise and ischaemic heart diseases (IHD) (van Kempen et al., 2018). A meta-analysis of 7 case-control or cohort studies led to a relative risk (RR) of 1.08 (95% CI: 1.01–1.15) per 10 dB L_{den} for the association between road traffic noise and the incidence of IHD. For aircraft noise, only two ecological studies (relative risk of 1.09 with 95% CI: 1.04–1.15) and for

railway and industrial noise no studies on the incidence of IHD were available. A plot of the association between road traffic noise and the incidence of IHD suggested that the risk of IHD increases continuously for road traffic noise levels from about 50 dB L_{den}.
For mortality due to IHD, in total 3 case-control and cohort studies were available for road traffic noise (relative risk of 1.05 per 10 dB L_{den} with 95% CI: 0.97–1.13) and one cohort study for aircraft noise (relative risk of 1.04 per 10 dB L_{den} with 95% CI: 0.98–1.11), both with similar relative risks as for the incidence studies and with overlapping 95% confidence intervals.

The guidance document concluded that given the small differences in relative risk for road traffic and aircraft noise and the notion that the underlying mechanism is similar for all noise sources, the relative risk from the studies with the highest quality can be applied in a health impact assessment for all noise sources. The study results of the longitudinal studies into the IHD incidence and mortality of road traffic noise have the highest quality and are therefore used for the other sources as well.
We follow in this report this advice. A meta-analysis published in 2015 into noise exposure from road traffic and aircraft noise led to similar findings (Vienneau et al., 2015). The combined relative risk was 1.06 per 10 dB L_{den} (95% CI: 1.03–1.09) using a reference level of 50 dB as starting level. There were no indications that the source of noise played a role in the relative risk.

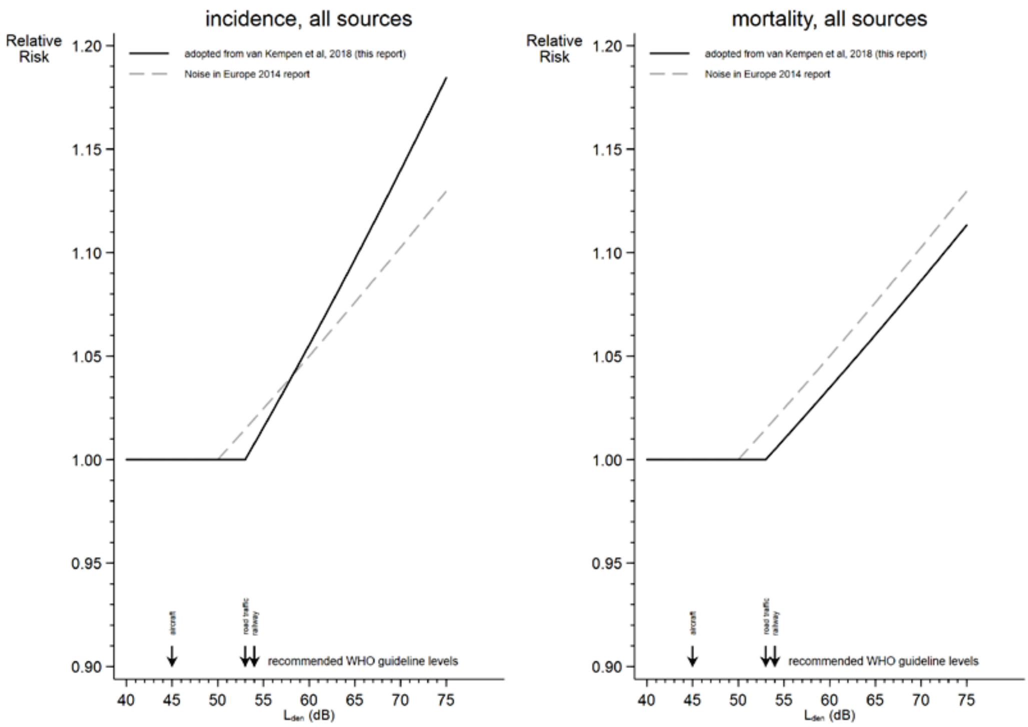
The GDG calculated a weighted average lowest exposure value of 53 dB L_{den} from the individual studies included in the meta-analyses for the association between road traffic noise and incidence of IHD to assess the starting noise level of the exposure-response relation. Also the guidance document recommends a threshold of 53 dB L_{den}. The value of 53 dB is slightly higher than the starting level of 50 dB L_{den} suggested in Vienneau et al., 2015 and van Kempen et al., 2018. Since the method applied by the CDG is the most transparent approach to assess the starting value, we took 53 dB L_{den} as starting point for the exposure-response relations and applied this value for all noise sources.

The formulas for the relation between the annual 24 hour noise level (L_{den}) and the relative risks for IHD incidence and mortality are given in Table 2-10. The relations are shown in Figure 2-4.

Table 2-10 **Relative risks for the incidence of ischaemic heart disease and mortality due to ischaemic heart disease in relation to the annual 24 hour noise level (L_{den}) for all four noise sources (road traffic, railway, aircraft and industrial noise) (adopted from van Kempen et al., 2018)**

Health endpoint	Noise source	Relative Risk
Incidence of IHD	all sources	RR= $\exp^{(\ln(1.08)/10*(Lden-53))}$ if L_{den}≥53 dB and RR=1 if L_{den} <53 dB
Mortality due to IHD	all sources	RR= $\exp^{(\ln(1.05)/10*(Lden-53))}$ if L_{den}≥53 dB and RR=1 if L_{den} <53 dB

Figure 2-4 **Relative risks for the incidence of ischaemic heart disease and mortality due to ischaemic heart disease in relation to the annual 24 hour noise level (L_{den}) for all four noise sources (road traffic, railway, aircraft and industrial noise) in this report and in the Noise in Europe 2014 report (adopted from van Kempen et al., 2018 and Vienneau et al., 2013)**



In the Noise in Europe 2014 report, the estimated relative risk for the combination of incidence and mortality reported in a conference paper (Vienneau et al., 2013) was applied (relative risk 1.05 per 10 dB L_{den}; 95% CI: 1.00-1.10) in combination with a threshold of 50 dB L_{den} (Houthuijs et al., 2014).

The plotted WHO guideline noise levels in Figure 2-4 are based on the probability of being highly annoyed. For road traffic and railway noise, the starting point of the relation is (almost) similar to the WHO guideline noise levels.

2.4 Estimation of the number of (additional or attributable) cases

In this section, it is summarised how the number of cases that are highly annoyed or highly sleep disturbed is calculated. For details of the calculations, we refer to the guidance document (van Kamp et al., 2018).

Reading impairment and the IHD incidence and mortality also occur in the absence of noise. For these health outcomes, it is described how the number of additional or attributable cases is estimated. The calculations are carried out for sub groups of the population as indicated in Table 2-2. The sources of the necessary demographic characteristics and baseline disease and mortality rates are addressed in a separate section.

All calculations are carried out on country level. In this report results will be reported for the EEA member countries (excluding Turkey) as one group. These results are based on the aggregated country results.

2.4.1 Number of adults which are highly annoyed per noise source

The number of adults (persons aged 18 years or older) that are highly annoyed from a specific noise source is calculated with the following equation:

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

With:

$n_{high\ annoyance}(L_{den})$:	*number of highly annoyed adults per noise category (L_{den})*
$n_{inhab}(L_{den})$:	*number of inhabitants per noise category (L_{den})*
f_{adults}:	*fraction of persons 18 years or older*
$\int_{annoyance}(L_{den}$, source):	*source-specific exposure-response function for high annoyance*

The source specific exposure-response function is described in Table 2-7. The function was applied in this report on the (estimated) mean exposure level of the 5 dB L_{den} categories (see section 2.2).

The total number of adults with high annoyance from a specific source is calculated by aggregating the number of highly annoyed persons over the relevant noise categories:

$$\sum_{L_{den}=min}^{max} n_{high\ annoyance}(L_{den})$$

With:

L_{den} = Min:	*the lowest noise exposure category;*
Max:	*the highest noise exposure category.*

In this report the aggregation took place over the 5 dB exposure categories reported in the framework of the END, so from 55 to over 75 dB L_{den}, unless specified otherwise.

2.4.2 Number of adults which are highly sleep disturbed per noise source

The number of adults (persons aged 18 years or older) that are highly sleep disturbed (HSD) from a specific noise source is calculated with the following equation:

$$n_{HSD}(L_{night}) = n_{inhab}(L_{night}) * f_{adults} * \int HSD\ (L_{night}, source)$$

Where:

$N_{HSD}(L_{night})$:	*number of highly sleep disturbed adults per noise exposure category (L_{night})*
$n_{inhab}(L_{night})$:	*number of inhabitants per noise exposure category (L_{night})*
f_{adults}:	*fraction of persons 18 years or older*
$\int_{HSD}(L_{night}$,source):	*source-specific exposure-response equation for highly sleep disturbed (see Table 2-8)*

The total number of adults with high sleep disturbance from a specific noise source is calculated by summing the number of highly sleep disturbed persons over the 5 dB exposure categories reported in the framework of the END, so from 50 to over 70 dB L_{night}, unless specified otherwise.

$$\sum_{L_{night}=Min}^{Max} n_{HSD}(L_{night})$$

With:

L_{night} = Min:	*the lowest noise exposure category;*
Max:	*the highest noise exposure category.*

2.4.3 Additional number of children with reading impairment associated with aircraft noise

Children at school are considered as population at risk. The number of children 7-17 years old with a reading impairment is calculated only for aircraft noise with the following equation:

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

With:

$n_{reading}(L_{den})$:	*Number of children 7-17 year old with reading impairment per aircraft noise exposure category (L_{den})*
$n_{inhab}(L_{den})$:	*Number of inhabitants per aircraft noise exposure category (L_{den})*
f_{7-17yr} :	*Fraction of children 7-17 year old*
$\int_{reading}(L_{den}, aircraft)$:	*Exposure-response equation for reading impairment associated with aircraft noise (see Table 2-9)*

The total number of children 7-17 years old with a reading impairment is calculated by summing up the number of children with reading impairment over the 5 dB exposure categories reported in the framework of the END, so from 55 to over 75 dB L_{den}:

$$N_{reading,noise} = \sum_{L_{DEN}=min}^{max} n_{reading}(L_{DEN})$$

With

L_{den}=*Min:*	*the lowest noise exposure category;*
Max:	*the highest noise exposure category.*

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

$$N_{reading,no\ noise} = \sum n_{inhab}(L_{den}) * f_{7-17yr} * f_{baseline}$$

With

$n_{inhab}(L_{den})$:	*Number of inhabitants per aircraft noise exposure category (L_{den})*
f_{7-17yr}	*Fraction children 7-17 year old*
$f_{baseline}$:	*Baseline probability: 0.1*

The additional number of children with a reading impairment associated with aircraft noise exposure is:

$$N_{reading,noise} - N_{reading,no\ noise}$$

2.4.4 Attributable number of cases of IHD incidence or mortality per noise source

It is common for the calculation of the number of incidence or mortality cases to make use of the population attributable fraction (PAF). The PAF is the proportional reduction in population disease or mortality that would occur if the exposure to a risk factor is reduced to an alternative ideal exposure scenario.

The PAF is calculated with the following equation:

$$PAF = \frac{\sum_{Lden=min}^{max} f_{inhab}(L_{den}) * RR(L_{den}) - \sum_{Lden=min}^{max} f_{inhab}(L_{den}, alt) * RR(L_{den})}{\sum_{Lden=min}^{max} f_{inhab}(L_{den}) * RR(L_{den})}$$

With:

$f_{inhab}(L_{den})$: The fraction of residents per exposure category (L_{den});

$f_{inhab}(L_{den},alt)$: The fraction of residents per exposure category (L_{den}) in an alternative, ideal exposure scenario

$RR(L_{den})$: The relative risk (RR) of the exposure category (L_{den}).

In this report, we define that an ideal exposure scenario does not lead to an excess risk (RR = 1). The equation above is subsequently written as:

$$PAF = \frac{\sum_{L_{den}=min}^{max} f_{inhab}(L_{den}) * (RR(L_{den}) - 1)}{(\sum_{L_{den}=min}^{max} f_{inhab}(L_{den}) * (RR(L_{den}) - 1)) + 1}$$

With:

L_{den}=Min: the lowest noise exposure category;

Max: the highest noise exposure category.

We refer to Table 2-10 for the calculation of the relative risk per noise exposure category. Since the relative risk differs between the incidence of IHD and the mortality due to IHD and the exposure distributions differ between noise sources, various PAFs are calculated.

The number of attributable incidence cases of IHD per year is calculated, per noise source, as follows:

$$n_{IHD,incidence,source} = PAF_{IHD,incidence,source} * incidence\ rate * \sum n_{inhab}(L_{den})$$

With

$PAF_{IHD,incidence,source}$: Population attributable fraction for incidence of IHD per noise source

Incidence rate: Incidence rate per year of IHD

$\sum n_{inhab}(L_{den})$: Total number of inhabitants in the considered noise exposure categories

In a similar way, the number of attributable deaths due to IHD per year is calculated per source:

$$n_{IHD,mortality,source} = PAF_{IHD,mortality,source} * mortality\ rate * \sum n_{inhab}(L_{den})$$

With

$PAF_{IHD,mortality,source}$: Population attributable fraction for mortality due to IHD per noise source

Mortality rate: Mortality rate per year of IHD

$\sum n_{inhab}(L_{den})$: Total number of inhabitants in the considered noise exposure categories

In the guidance document, it is indicated that the calculations should be carried out for adults since the relative risks are obtained from studies among adults. For reasons of convenience, we carry out the calculations for the total population since the incidence and mortality due to IHD at younger ages is very small or absence. This choice will not affect the results.

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. We used the $PAF_{IHD,incidence}$ for the calculation of the YLD and $PAF_{IHD,mortality}$ for the calculations of the YLL. The calculations are carried out for each noise source separately.

$$YLD_{IHD,source} = PAF_{IHD,incidence,source} * YLD_{IHD} * \sum n_{inhab}(L_{den})$$

and

$$YLL_{IHD,source} = PAF_{IHD,mortality,source} * YLL_{IHD} * \sum n_{inhab}(L_{den})$$

With

$PAF_{IHD,incidence,source}$:	*Population attributable fraction for incidence of IHD per noise source*
$PAF_{IHD,mortality,source}$:	*Population attributable fraction for mortality due to IHD per noise source*
YLD_{IHD}:	*Baseline years lived with disease (YLD) due to IHD per year*
YLL_{IHD}:	*Baseline years of life lost (YLL) due to IHD per year*
$\sum n_{inhab}(L_{den})$:	*Total number of inhabitants in the considered noise exposure categories*

2.4.5 Baseline demographic and disease and mortality data

Demographic and disease data is necessary to carry out the calculations as specified in the previous sections.
Data on the age distribution was downloaded from Eurostat for January 1, 2012 and January 1, 2017. The resolution is one-year intervals. For each of the countries, the number of 7-17 years old children and the number aged 18 year or older was calculated as fraction of the total population. For countries for which Eurostat did not provide information, data on the age distribution based on five-year intervals from the Worldbank was used to estimate the fraction 7-17 years old children and the fraction aged 18 year or older.

Data for 2011 and 2016 on the incidence and mortality rate for IHD as well as on YLD and YLL was downloaded from the website of the Institute for Health Metrics and Evaluation (IHME). At the time of preparing this report, WHO did not report 2016 data for these disease and mortality endpoints yet. For countries not included in the IHME dataset, we imputed the missing data with the averaged results of the neighbouring countries.

2.5 Additional analyses

Additional analyses are carried out to evaluate the consequence of changes in the methodology and to assess the sensitivity of the results for choices in the assessment like double counting and the disability weights. We introduce these analyses in the following sections.

2.5.1 Effect of the update of the exposure-response relations

We calculated the impact of highly annoyed, highly sleep disturbed, reading impairment and cardiovascular disease (IHD and stroke) with the exposure-response relations used for the Noise in Europe 2014 report to assess the effect of the update of the relations. These “old” relations were already briefly introduced in the previous sections. For details, we refer to Houthuijs et al. (2015).
The demographic, disease and mortality data was kept identical in this additional analysis although also this baseline data was updated compared with the data used in the Noise in Europe 2014 report (see for details Houthuijs and de Leeuw, 2018).

2.5.2 Estimation of potential double counting

2.5.2.1 Introduction

Most studies on environmental noise focus on source-specific impacts on health and well-being outcomes and do not take combined effects of multiple noise sources into account. Also the GDG did not

make an attempt to combine noise from multiple sources for any particular health outcome (WHO, 2018), so there is little knowledge and experience about how to combine the effects of different sources in a health impact assessment. The GDG described that the effects of their recommended health outcomes for a health impact assessment are cumulative, but without further elucidation. On the other hand, in several publications on noise caution is advised when evaluating the total burden from different health endpoints as there is potential for double counting.
We first briefly touch upon different meanings of “double counting” and their relevance for the health impact described in this report. Subsequently, we will describe some methods to estimate the potential double counting.

The expression “double counting” is used in the noise field in different ways. We will discuss four of them to make transparent which form of double counting we address in this report.

1. *Part of the same causal pathway*

Double counting can occur when health endpoints are valued that are part of the same causal pathway of health effects. For example, hypertension is an important (but not exclusive) risk factor for cardiovascular disease later in life. So valuating both hypertension and cardiovascular disease will lead to double counting. WHO (2018) describes in the justification of the selection of annoyance and sleep disturbance as critical health outcomes that these endpoints may be in the causal pathway to cardiovascular disease. In a paper on biological mechanisms of noise prepared in the context of the WHO Environmental Noise Guidelines for the European Region (Eriksson et al., 2018), it was concluded that long-term night-noise exposure may be of greater importance for long-term effects of noise than daytime exposure, so potential double counting is likely to be more relevant for noise-induced sleep loss than for annoyance. Since there is little known about the precise interrelation between sleep disturbance and cardiovascular disease, this type of potential double counting cannot be addressed in a quantified way.

2. *Overlapping health endpoints or populations at risk*

There is potential double counting when the definition of health endpoints overlap each other and/or when exposure-response relations for the general population includes specific populations at risks for which a separate quantification is also suggested. Morbidity outcomes are more vulnerable for this type of double counting than mortality outcomes. The health outcomes used in this report are among others selected to reduce double counting due to health definitions, although some remaining double counting is possible.

3. *Exposure to multiple noise sources*

In the case of noise exposure from multiple sources, the health risks from one source may be modified by the exposure from another noise source. The modification affects the combined risk: it may become larger or smaller than the sum of the individuals risks. Potential double counting may occur when the modification of the risk is not taken into account and the health impact is based on the risks of the individual sources.

4. *Monetarisation of noise effects*

Hedonic pricing (using house prices) is often used to assess the monetary value of the effects of noise. In case that health outcomes like annoyance and sleep disturbance are also valuated (for example using Willingness To Pay), double counting of the external costs of noise may occur. It is unknown how much external cost of noise overlap when combinations of methods for monetarisation are used. Since monetarisation of noise effects is not the scope of this report, this type of potential double counting will not be addressed.

Below, we will discuss the potential double counting in the case of noise exposure from multiple noise sources (type 3). An import methodological issue is the distinction between 1) the combined risks of multiple noise sources on individual level and 2) the combined impact of multiple noise sources on population level.

2.5.2.2 Combined risks of multiple noise sources on individual level

Double counting introduced by risk modification due to noise exposure from multiple source can be overcome if the noise exposure to all (relevant) sources in known on individual level. In theory, we can then model their joint effect on individual level and use the result in a health impact assessment. Unfortunately, the END data is reported per noise source for assessment areas in major agglomerations and major sources which does not allow this approach on individual level.
Nevertheless, we will briefly illustrate this approach since it will give insight in the direction that may be followed to quantify the joint effects of multiple noise sources.

The statistical models used in studies into effects on IHD are logistic regression or Cox proportional hazard models. These models are so-called multiplicative models. In this type of model, the combined effect of multiple risk factors is larger than when we consider the summed risk of individual risk factors from a multiplicative model. This is illustrated with an example in Table 2-11 for the incidence of IHD. We assume that the home of an individual is exposed to road traffic, railway, aircraft and industry noise, each with an exposure level of 63 dB L_{den}. The associated relative risk (RR) for the incidence of IHD is 1.08 per noise source.

Table 2-11 Increase in relative risk for the incidence of IHD in relation to the number of noise sources with an individual relative risk of 1.08 in a multiplicative model and in added results of individual models

Number of noise sources with an individual relative risk of 1.08	Increase in relative risk (RR-1) for incidence of IHD	
	Multiplicative model	Sum of individual models
1	0.08	0.08
2	0.17	0.16
3	0.26	0.24
4	0.36	0.32

Table 2-11 shows that the combined risk in a multiplicative model is larger than the added risk of individual multiplicative models. In this example, the combined risk of the four noise sources for the incidence of IHD is 12% larger than when the sum of the risk of the four individual sources is considered.
If a multiplicative model is a valid model for the combined effects of noise on cardiovascular disease, there is no obvious problem with double counting. The example illustrates that the risk of the combined exposure may be underestimated when the impact of individual sources is reported.

For annoyance, a method called equal annoyance weighting was introduced to estimate the total annoyance due to combined noise exposures (Miedema, 2004). This method was recommend by EEA's Good practice guide on noise exposure and potential health effects (EEA, 2010). An example is used to illustrate this method.
Assume a situation with two relevant noise sources: road traffic and railway noise. It is common practise to start with converting the noise exposure from the source not being road traffic (in this case railway noise) to an equal annoyance road traffic noise exposure level. Subsequently, the obtained equal annoyance road traffic noise exposure level for this source is energetically added to the road traffic exposure level. Lastly, the probability of highly annoyed is assessed with the exposure-response relation for road traffic noise using the obtained weighted exposure level. This procedure leads to a lower probability of being highly annoyed than when the probabilities of annoyance from the separate sources are added. The procedure may have to be revisted in the light of the updated exposure-response relations which indicates that in END assessment areas railway noise is more annoying than road traffic noise at the same exposure level.

The equal annoyance weighting is an attractive procedure since it is transparent. However, there are also other models to take into account total annoyance. Pierrette et al. (2012) summarised six classical total annoyance models in the case of two noise sources:

- *The strongest component model:* This model states that the total annoyance is equal to the maximum of the annoyances of the noise sources.
- *The linear regression model.* This model states that the total annoyance is a weighted summation of specific annoyances.
- *The vector summation model:* This model implies that the total annoyance is derived from a vector addition of the specific annoyances of the sources.
- *The energy summation model:* In this model, the total annoyance is a function of the total noise level.
- *The independent effects model:* The total annoyance is a function of the noise levels of the relevant noise sources.
- *The energy difference model*. The total annoyance is a function of the total noise level and of the absolute difference between the noise levels of the relevant noises.

When one noise source is much more annoying than the other, the strongest component model often leads to a good prediction. However, when the annoyance values from different noise sources are close, the strongest component model neglects the possible influence on total annoyance of the specific annoyance due to the least annoying source.

2.5.2.3 Combined impact of multiple noise sources on population level

The END requires the collection of population exposure levels in hotspots (around major sources and within major agglomerations).

END population exposure data on major sources is not suitable to assess the combined impact of multiple noise sources, since it is not known what the exposure levels of other sources are in the assessment area of the concerning major source. However, with the following assumptions, we can estimate the combined impact of annoyance:

- the major source is the dominant noise source in the concerning assessment area and this source leads to the highest probability for annoyance, and
- the assessment areas of the major sources are geographically spread and do not overlap.

Given the focus of the END on the hotspots, these assumptions seem a reasonable point of departure. We can therefore apply the above described strongest component model in the assessment areas of the major sources. Total annoyance is in this model equal to the maximum of the annoyances of the relevant noise sources, in this case, the concerning major source. The possible influence on the combined annoyance of other sources is assumed to be neglectable. As a consequence, we can add up the impacts of annoyance in the major source assessment areas without being concerned about double counts.

For major agglomerations, it is much more likely that there is overlap in assessment areas. From the EEA Noise in Europe 2014 report we know that road traffic noise is the dominant source in the major agglomerations. If we assume that in the case of exposure to multiple sources, road traffic noise is always one of the noise sources present and also the source that leads to the highest probability of being annoyed, the strongest component model for total annoyance will lead to an estimated impact that is equal to the impact of road traffic noise only. Deviations of these assumptions (road traffic is not one of the combined sources, or road traffic is not the source with the highest probability for being annoyed) will result in an additional impact of annoyance due to railways, aircrafts or industry. So the burden of annoyance related to road traffic noise is the minimum estimate for the burden of total noise annoyance in the major agglomerations.

The estimations for the burden of total annoyance in the major agglomerations and in the assessment areas of the major sources can be added up, since the agglomerations and the assessment areas of the major sources are spatially separated.

We applied the above described method to estimate the double counting for sleep disturbance as well. There are studies on the number of additional awakenings in relation to noise events from multiple sources. The results of these studies are not applicable since the impact described in this report is based on an exposure-response relation for self-reported sleep disturbance related to L_{night}.

For the combined effect of noise sources on IHD incidence and mortality, we can apply a method that is often applied in public health when the combined impact of multiple risk factors for a population is evaluated. For the joint impact of multiple noise sources, we calculate a combined population attributable fraction (PAF) from the PAFs of the individual sources:

$$PAF_{combined} = 1 - \left\{(1 - PAF_{road}) * (1 - PAF_{rail}) * (1 - PAF_{aircraft}) * (1 - PAF_{industry})\right\}$$

If each of the noise sources have a PAF of 0.075, the result for the combined PAF is slightly less than 0.28. If we calculate the sum of the additional impacts, we assume a combined PAF of 0.30. This example indicates that double counts are limited if the PAFs are below 0.10 and the number of sources is small.

To apply the formula above, it is necessary that the PAFs of the individual sources are calculated for the same underlying population, since it is not possible to combine the PAFs of different populations. Again, we have to make assumptions about the combined exposure in the different END assessment areas.

For the assessment areas related to major sources, we assume that other noise sources than the major source of concern have exposure levels that do not imply a risk for IHD. If this assumption is valid, the PAFs of these sources are zero. Applying the formula leads to the obvious result that the combined PAF is equal to the PAF of the noise source of concern. We already assumed for annoyance that the assessment areas of the major sources are geographically spread and do not overlap. So, if these assumptions are valid the burden of disease due to IHD of the major sources can be combined without a risk of double counting.

For major agglomerations, we recalculated the PAF for the four noise sources (on country level). A relative risk of 1 was assumed for the population living inside the major agglomerations but located outside the assessment areas of the noise source under concern. We ignored that the relative risk for the population exposed between 53 and 55 dB L_{den} is higher than 1.
The recalculation will lead to a lower individual PAF for the four noise sources. However, the PAFs have to be applied to a larger population (the whole agglomeration and not only the population above 55 dB L_{den}). This population is now made identical for all four sources, so their PAFs can be pooled to a combined PAF and the combined impact for IHD can be calculated.

2.5.3 Effect of choices in the disability weight for the assessment of the burden of disease due to environmental noise

It is possible to convert the estimated number of adults that are highly annoyed or highly sleep disturbed and the number of children with a reading impairment into Years Live with Disease (YLD), so the impact of these outcomes can be combined with the impact of IHD (YLD and YLL). Years Live with Disease and Years Life Lost can be added up to obtain Disability Adjusted Life Years (DALYs).

For the calculation of the YLD for highly annoyed, highly sleep disturbed and reading impairment, three ingredients are necessary that have to multiplied to obtain the YLD:

- The number of (additional) cases (already discussed in section 2.4.1 to 2.4.3),
- The disability weight of the condition,
- The duration of the condition. The condition for all three endpoints is one year and needs no further elaboration.

Table 2-12 gives an overview of the proposed disability weights for highly annoyed, highly sleep disturbed and reading impairment and that were extensively discussed in studies on the burden of disease from environmental noise.

Table 2-12 Overview of proposed disability weights for highly annoyed, highly sleep disturbed and reading impairment for the assessment of burden of disease due to environmental noise

Health endpoint	Disability weight	Source
Highly annoyed	0 0.01 0.02	WHO (2012), van Kamp et al. (2018) van Kamp et al. (2018) WHO (2011)
Highly sleep disturbed	0.0175 0.07	van Kamp et al. (2018) WHO (2009, 2011, 2012)
Reading impairment	0 0.006	WHO (2012), van Kamp et al. (2018) WHO (2011)

We give some background on the value of the disability weights tabled.

The WHO Burden of disease from environmental noise report discussed disability weights for various health endpoints and proposed a set of weights to be used in a health impact assessment of noise WHO (2011). At that time there was discussion whether annoyance should be included in a health impact assessment. It was concluded that annoyance does affect the well-being of many people and therefore may be considered to be a health effect falling within WHO definition of health. The leaves the question open whether noise annoyance contribute to disability and should be taken into account. If severe annoyance is quantified in a health impact assessment, WHO (2011) proposed a disability weight of 0.02.
For sleep disturbance, WHO indicated that induced sleep disturbance is not the same as primary insomnia, but that the severity of primary insomnia and noise-induced environmental sleep disorder might be similar. At that time, the disability weight of primary insomnia was 0.10 (WHO, 2004); this weight was provisionally assessed for the 1990 Global Burden of Disease study. WHO (2011) proposed a disability weight of 0.07 for highly sleep disturbed, following the WHO Night noise guidelines for Europe (WHO, 2009).
WHO (2011) provides a disability weight of 0.006 for noise-related impairment of children's cognition. This weight was based on the weight for contemporaneous cognitive deficit, a reduction in cognitive ability in school-age children.
The Guideline Development Group used in 2013 among others the above mentioned disability weights to prioritize the health endpoints for the Environmental Noise Guidelines for the European Region (WHO, 2018).

The project EBODE (Environmental Burden of Disease in the European region) established and tested a harmonized methodology to assess the environmental burden of disease of noise, air pollution, radon, benzene, indoor air pollution and dioxins in 6 European countries (Hänninen and Knol, 2011; Hänninen et al., 2014). A special meeting was organised to discuss the methodology for the calculation of DALYs for environmental noise (WHO, 2012). It was concluded to use sleep disturbance and IHD as indicators for environmental noise in a health impact assessment. The disability weight for sleep disturbance was adopted from WHO (2011). In the meeting report it is stated that annoyance and reading impairment should not be part of such an exercise. We converted this statement in a disability weight of 0 in Table 2-12.

The guidance document (van Kamp et al., 2018) uses the results of a study of Haagsma et al. (2015) to derive a new disability weight for sleep disturbance (0.0175). The aim of the study of Haagsma et al. was to estimate disability weights for Europe for a set of 255 health states, including 43 new health states, by replicating the GBD 2010 Disability Weights Measurement study among over 30,000 responders in four European countries. Insomnia is mentioned as a new health outcome: its weight was 0.023. In the WHO report (WHO, 2011) a Swiss study is described in which 14 general practitioners were asked to compare the relative mean severity of the health state of person with obstructive sleep apnoea syndrome (OSAS) with primary insomnia or with sleep disturbance due to increased road noise exposure. Based on their professional judgement, 9 of the 14 practitioners considered noise related sleep disturbance on average less serious than primary insomnia. The mean judgement of the 14 respondents was that noise-related sleep disturbance has a mean severity of 0.9 times the severity of primary insomnia (median 0.63). Based on these results, van Kamp et al. recommended a disability weight for highly sleep disturbed of 0.0175 (0.63 to 0.90 times the disability weight of primary insomnia assessed by Haagsma et al.).
High annoyance was in the guidance document considered as less severe than high sleep disturbance. Given the update on highly sleep disturbed, highly annoyed received an ad-interim disability weight of 0.01 (when annoyance is part of the health impact assessment). Van Kamp et al. indicate that in the literature several arguments can be found why annoyance might not qualify as a health endpoint in DALY calculations. So when it is decided to exclude annoyance, the guidance document indicates a disability weight of 0.
There is no recommendation in the guidance document for the disability weight or children's reading impairment due to aircraft noise. We converted this as a disability weight of 0 in Table 2-12.

The choice of the disability weight has consequences for the outcome of the burden of disease assessment. We will assess the consequences by calculation the burden of disease using various disability weights. We use the total impact that is obtained for highly annoyed, highly sleep disturbed and reading impairment with the 2012 END data.

3 Results

The summarised results described in this Chapter are for 32 countries (EEA members countries, except Turkey), unless specified otherwise. The (population-weighted) results are based on 517 million inhabitants in 2012 and 526 million in 2017.
The reported noise exposure data of the second and third round was used to calculate the health implications in all individual countries according to the methods described in Chapter 2. These results are part of the country factsheets that are provided by the EEA.

3.1 Descriptive results

3.1.1 Noise exposure

Tables 3-1 and 3-2 provide the average exposure levels in the 5 dB categories for L_{den} and L_{night} in 2012 by source and summarise the exposure distributions with a population weighted average noise level equal or above 55 dB L_{den} and equal or above above 50 dB L_{night}.

Table 3-1 presents the results within major agglomerations. About 183 of the 517 million inhabitants in the EU28, Iceland, Liechtenstein, Norway and Switzerland lived in 2012 in the major agglomerations. It is estimated that almost 96 million of them are located in an assessment area for the L_{den} (almost 85 million in the reported data, 88% of the gap filled number) and almost 68 million (60 million reported, 89%) in an assessment area of the L_{night}. Inhabitants can live in multiple assessment areas of L_{den} or L_{night}: double counts cannot be excluded.

Table 3-1 Average exposure per 5 dB noise category within major agglomerations in 2012 (EU28, Iceland, Liechtenstein, Norway and Switzerland)

Exposure Category	Road traffic (dB)	Railway (dB)	Aircraft (dB)	Industry (dB)
L_{den}				
55 - 59 dB	57.26	57.33	57.08	56.70
60 - 64 dB	62.41	62.23	61.96	62.03
65 - 69 dB	67.32	67.17	66.91	67.02
70 - 74 dB	72.13	72.10	71.78	72.21
>75 dB	76.80	77.06	77.00	77.36
Population weighted average over categories	62.87	61.16	58.75	58.94
L_{night}				
50 - 54 dB	52.26	52.32	52.04	51.97
55 - 59 dB	57.31	57.18	56.87	56.94
60 - 64 dB	62.16	62.12	61.86	62.19
65 - 69 dB	66.93	67.07	66.81	67.29
>70 dB	71.72	72.05	71.50	72.43
Population weighted average over categories	56.17	55.71	53.26	54.38

Table 3-2 gives the results for major sources. About 41 million inhabitants are estimated to live in the assessment areas of the L_{den} (almost 40 million reported, 96% of the gap filled number) and about 28 million in the assessment areas of the L_{night} (27 million reported, 96%). Since the assessment areas of the major source are likely to be spread geographically more than the assessment areas within agglomerations, double counting is expect to be a small issue for major sources.

Table 3-2 **Average exposure per 5 dB noise category for major sources in 2012 (EU28, Iceland, Liechtenstein, Norway and Switzerland)**

Exposure Category	Road traffic (dB)	Railway (dB)	Aircraft (dB)
L_{den}			
55 - 59 dB	57.38	57.38	57.03
60 - 64 dB	62.32	62.20	61.83
65 - 69 dB	67.32	67.19	66.76
70 - 74 dB	72.13	72.22	71.73
>75 dB	76.73	77.14	77.03
Population weighted average over categories	61.21	61.53	58.21
L_{night}			
50 - 54 dB	52.41	52.31	51.97
55 - 59 dB	57.32	57.19	56.86
60 - 64 dB	62.19	62.18	61.88
65 - 69 dB	66.84	67.21	66.97
>70 dB	71.69	72.09	
Population weighted average over categories	56.45	56.29	52.86

The results in Table 3-1 and 3-2 indicate that the average exposure level per exposure category does not differ substantially from the midpoint value of the category. The largest differences are found for aircraft noise, reflecting that the number of inhabitants increases more rapidly at lower exposure levels than is the case for the other noise sources.
The highest average exposure level is found for road traffic noise and the lowest level for aircraft noise.

The results for 2017 of the exposure in the major agglomerations are given in Table 3-3.

Table 3-3 **Average exposure per 5 dB noise category within major agglomerations in 2017 (EU28, Iceland, Liechtenstein, Norway and Switzerland)**

Exposure Category	Road traffic (dB)	Railway (dB)	Aircraft (dB)	Industry (dB)
L_{den}				
55 - 59 dB	57.24	57.33	57.06	56.67
60 - 64 dB	62.40	62.22	62.01	62.06
65 - 69 dB	67.31	67.17	66.83	67.04
70 - 74 dB	72.13	72.06	71.81	72.19
>75 dB	76.81	77.04	76.97	77.35
Population weighted average over categories	62.77	61.04	58.76	59.15
L_{night}				
50 - 54 dB	52.23	52.32	52.02	51.94
55 - 59 dB	57.31	57.19	56.83	56.95
60 - 64 dB	62.16	62.12	61.75	62.21
65 - 69 dB	66.95	67.04	66.90	67.28
>70 dB	71.72	72.00	71.50	72.37
Population weighted average over categories	56.14	55.66	53.24	54.31

In 2017, about 185 million of the 526 inhabitants live in the major agglomerations. Compared with 2012, information about a substantial part of the agglomerations is still missing. Based on the gap filled dataset, it is estimated that almost 93 million inhabitants are located in an assessment area for the L_{den}. So far, 51% of the gap filled number is reported (over 47 million inhabitants). For the assessment areas of the L_{night} 31 million inhabitants are reported while it is estimated that 64 million inhabitants live in these areas (indicative completeness 49%). Again, double counts may be included in these numbers.

Table 3-4 provides the results for major sources in 2017. Almost 42 million inhabitants are estimated to live in the assessment areas of the L_{den} (almost 22 million reported; indicative completeness 52%) and 29 million in the assessment areas of the L_{night} (over 14 million reported, 50%).

Table 3-4 Average exposure per 5 dB noise category for major sources in 2017 (EU28, Iceland, Liechtenstein, Norway and Switzerland)

Exposure Category	Road traffic (dB)	Railway (dB)	Aircraft (dB)
L_{den}			
55 - 59 dB	57.31	57.33	57.06
60 - 64 dB	62.30	62.18	61.81
65 - 69 dB	67.32	67.17	66.74
70 - 74 dB	72.10	72.19	71.69
>75 dB	76.72	77.12	76.50
Population weighted average over categories	62.12	61.26	58.45
L_{night}			
50 - 54 dB	52.30	52.31	52.05
55 - 59 dB	57.32	57.18	56.80
60 - 64 dB	62.19	62.17	61.61
65 - 69 dB	66.77	67.19	66.50
>70 dB	71.72	72.10	-
Population weighted average over categories	56.33	56.16	53.25

Since the results in Table 3-3 and Table 3-4 are based for about 50% on imputed data, we are hesitant with an interpretation. We just conclude that the results for 2017 are similar to the results for 2012.

3.1.2 Demographic, disease and mortality

Table 3-5 describes the used demographic, disease and mortality data used for 2012 and 2017. The information of the individual countries can be found in Annex 4 (for 2012) and Annex 5 (for 2017).

Table 3-5 **Demographic, disease and mortality data used for 2012 and 2017 (EU28, Iceland, Liechtenstein, Norway and Switzerland)**

Characteristic	Mean	Minimum	Maximum
2012:			
Fraction 7-17 years old	0.10460	0.08621	0.13442
Fraction adults	0.81055	0.74831	0.83876
Incidence rate IHD pp py	0.00512	0.00269	0.00817
Mortality rate IHD pp py	0.00203	0.00111	0.00515
YLD IHD pp py	0.00185	0.00125	0.00296
YLL IHD pp py	0.02512	0.01282	0.07272
2017:			
Fraction 7-17 years old	0.10514	0.09026	0.13841
Fraction adults	0.81250	0.75043	0.83677
Incidence rate IHD pp py	0.00509	0.00284	0.00830
Mortality rate IHD pp py	0.00210	0.00110	0.00542
YLD IHD pp py	0.00195	0.00137	0.00322
YLL IHD pp py	0.02457	0.01259	0.07328

The minimum and maximum values in Table 3-5 reveal that there are still substantial differences in the incidence of and mortality due to IHD between countries in Europe (up to a factor 3 for incidence and up to 5 for mortality). Also the results indicate that, on average, about 12-14 times more years are lost due to mortality (YLL) due to ischaemic heart disease (IHD) than there are years lived with a disability due to IHD (YLD).

3.2 Key findings health impact assessment 2012

The key findings presented are aggregates of the results for 32 countries (EU28, Iceland, Liechtenstein, Norway and Switzerland). The endpoints considered were highly annoyed, highly sleep disturbed, reading impairment and IHD incidence and mortality.

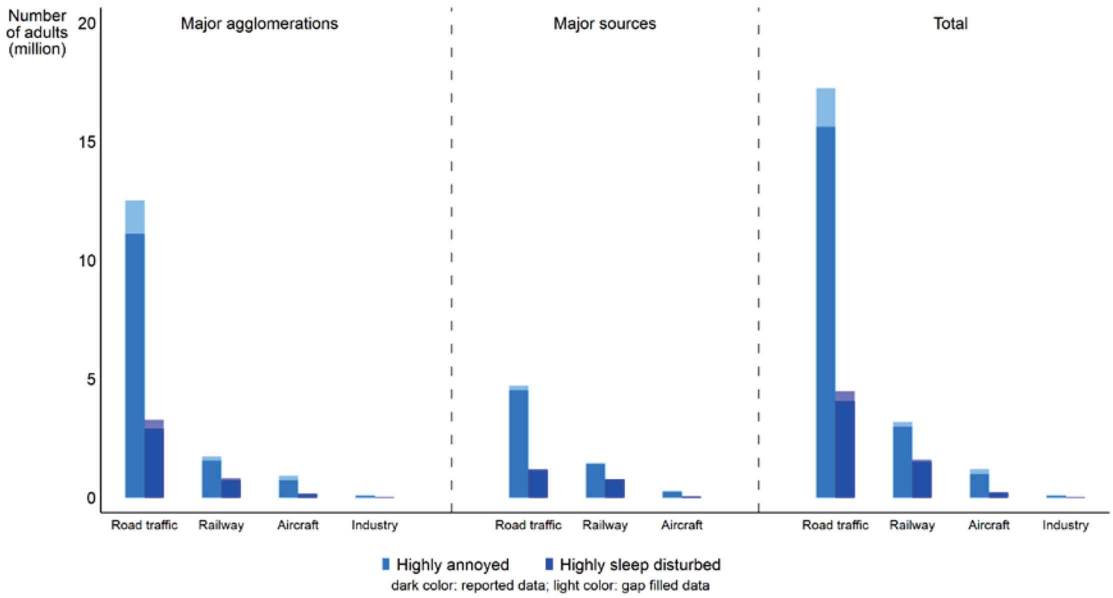
3.2.1 Highly annoyed and highly sleep disturbed

Based on the noise data reported by the countries for 2012, around 19.7 million adults living in agglomerations or near major sources with noise levels equal to or above 55 dB L_{den} may be considered as being 'highly annoyed' by noise from road traffic, railways, aircrafts or industry. Adding the gap filled END data increases the total number of adults being highly annoyed by noise to around 21.7 million.

Similar, it was assessed that 5.8 million adults are highly sleep disturbed due to night time noise levels equal to or above 50 dB L_{night} from road traffic, railways, aircrafts or industry. Supplementing the reported END data with gap filled data, the impact is enlarged to 6.4 million adults that are highly sleep disturbed.

In Figure 3.1, the results for highly annoyed and highly sleep disturbed based on the reported and gap filled END data are presented according to the noise source and the location of the assessment.

Figure 3-1 **Estimated number of adults which are highly annoyed and estimated number of adults that are highly sleep disturbed according to the noise source and location of the assessment, based on the reported and gap filled END data 2012 (EU28, Iceland, Liechtenstein, Norway and Switzerland)**



As shown in the figure based on the reported and gap filled END data, 70-80% of the burden of annoyance and sleep disturbance is related to road traffic noise, of which about 73% occurs in the agglomerations.

3.2.2 Reading impairment and IHD incidence and mortality

It is estimated that 13.300 children in the age of 7 to 17 year old have a reading impairment attributed to exposure to noise from aircrafts. Three quarters of them are children in agglomerations.

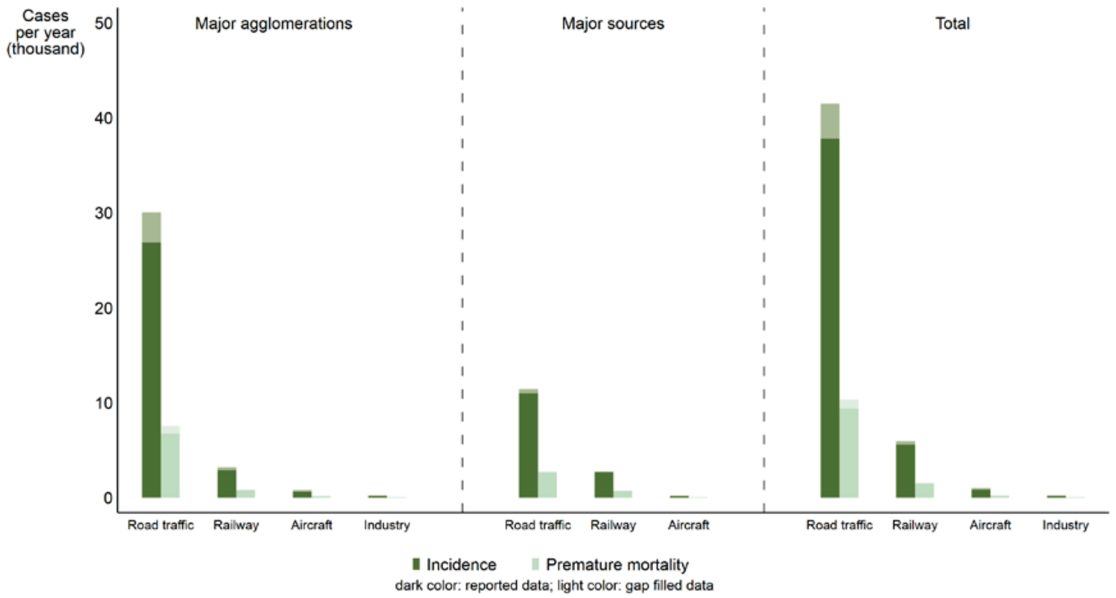
The incidence of IHD related to noise exposure is estimated to be over 44.000 cases per year, based on the reported data and almost 49.000 cases per year, based on reported and gap filled END data.

For mortality due to IHD, it is estimated that noise could contribute to 11.100 premature deaths per year, based on the reported data; and 12.200 deaths per year based on reported and gap filled data.

Based on the gap filled dataset, it is estimated that related to the noise exposure attributable IHD cases in 2012 about 17 thousand years were lost due to disability and about 150 thousand years of life lost due to premature mortality.

In Figure 3-2, the results for the incidence and premature mortality based on the reported and gap filled END data are presented according to the noise source and the location of the assessment.

Figure 3-2 **Estimated cases per year of incidence and premature mortality due to ischaemic heart diseases, according to the noise source and location of the assessment based on the reported and gap filled END data 2012 (EU28, Iceland, Liechtenstein, Norway and Switzerland)**



About 85% of the incidence and premature mortality due to IHD is related to road traffic noise, of which over 70% occurs in the agglomerations.

3.3 Key findings health impact assessment 2017

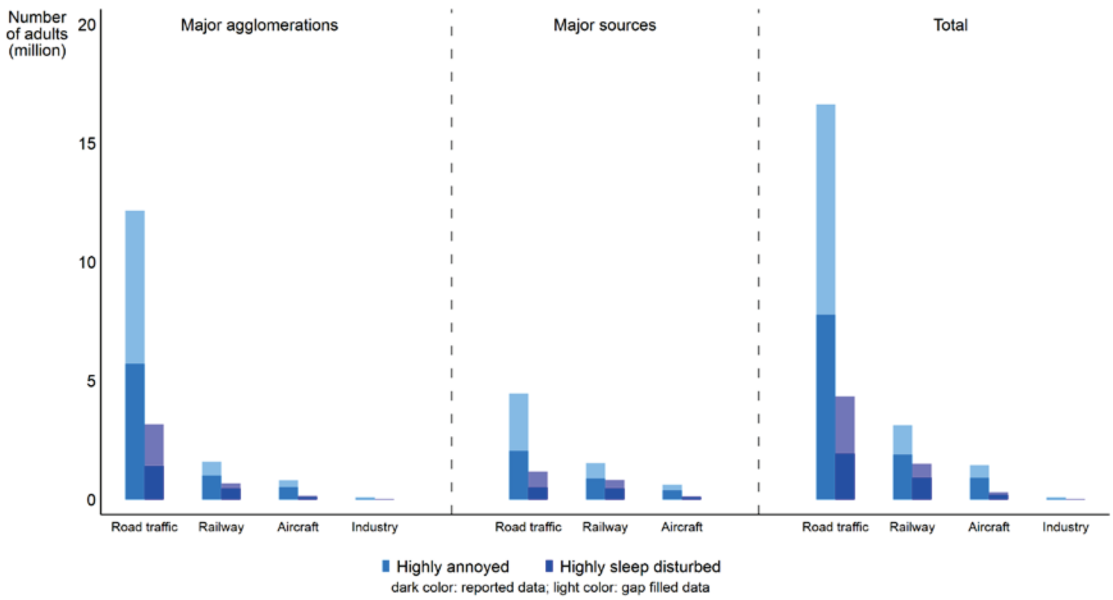
The health impact assessment 2017 is based for about 50% on reported and about 50% on imputed noise exposure data.

3.3.1 Highly annoyed and highly sleep disturbed

Around 10.6 million adults living in the assessment areas for L_{den} in agglomerations or near major sources are being ‘highly annoyed’ by noise from road traffic, railways, aircrafts or industry based on the reported data so far for 2017. The total number of adults being highly annoyed by noise doubles to around 21.3 million when the reported and gap filled datasets are used The total number of adults that are highly sleep disturbed are 3.0 million based on reported data and 6.2 million based on reported and gap filled data. The totals based on reported and gap filled data are in 2017 almost identical to the total numbers in 2012.

The results for highly annoyed and highly sleep disturbed are shown according to the noise source and the location of the assessment in Figure 3-3.

Figure 3-3 **Estimated number of adults which are highly annoyed and estimated number of adults that are highly sleep disturbed according to the noise source and location of the assessment, based on the reported and gap filled END data 2017 (EU28, Iceland, Liechtenstein, Norway and Switzerland)**



Similar to 2012, in 2017 about 70-80% of the burden of annoyance and sleep disturbance is related to road traffic noise, of which about 70-75% occurs in the agglomerations.

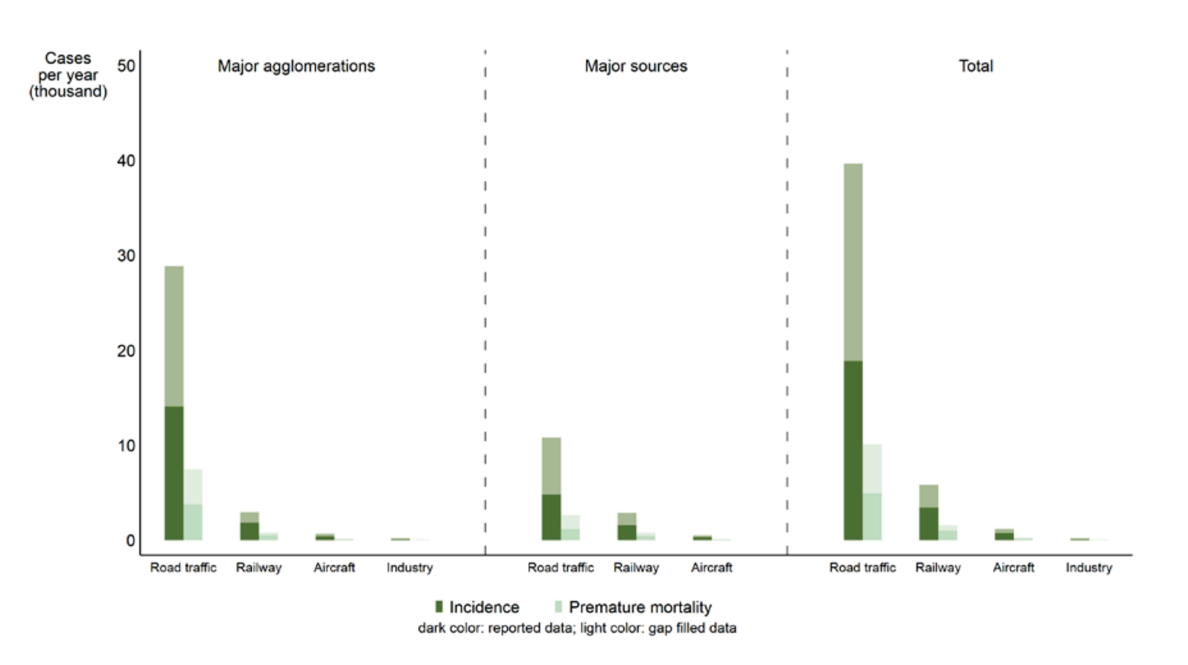
3.3.2 Reading impairment and IHD incidence and mortality

It is estimated that in 2017 over 16.000 children in the age of 7 to 17 year old have a reading impairment related to exposure to noise from aircrafts. 70-75 Percent of them are children in agglomerations.

The incidence of IHD attributed to noise exposure is calculated to be over 23.000 cases per year, based on the reported data and doubles to about 47.000 cases per year, based on reported and gap filled END data. For premature mortality, the numbers are respectively 6.100 and 12.000 premature deaths per year. Based on the imputed dataset, it is estimated that the incidence and mortality due to IHD leads to about 17 thousand years lost due to disability and almost 140 thousand years of life lost due to premature mortality. These results for 2017 are almost identical to the results for 2012.

In Figure 3-4, the results for the incidence and premature mortality based on the reported and gap filled END data are presented according to the noise source and the location of the assessment.

Figure 3-4 **Estimated cases per year of incidence and premature mortality due to ischaemic heart diseases, according to the noise source and location of the assessment based on the reported and gap filled END data 2017 (EU28, Iceland, Liechtenstein, Norway and Switzerland)**



Again, almost 85% of the disease burden is related to road traffic noise, of which about 70-75% occurs in the agglomerations.

3.4 Effect of the update of the exposure-response relations

The impact of the update of the exposure-response relations is explored by comparing the impact described in section 3.3 with the impact calculated with the relations used for the Noise in Europe 2014 report. The comparison is done for 2012 since this dataset is mostly based on reported data and contains only a limited amount of imputed data.

The results for highly annoyed and highly sleep disturbed are presented in Table 3-6. The results for the incidence of IHD are presented in Table 3-7. In the Noise in Europe 2014 report also stroke was quantified; this health endpoint is added to the table.

Table 3-6 **Effect of the update of the exposure-response relations for highly annoyed and highly sleep disturbed according to the noise source, based on the reported and gap filled END data for 2012 (EU28, Iceland, Liechtenstein, Norway and Switzerland)**

Noise source	Impact among adults (*1,000,000)		Change (%)
	"new" relations	"old" relations	
Highly annoyed:			
Road traffic	17.2	13.3	+29
Railway	3.2	1.0	+206
Aircraft	1.2	1.3	-10
Industry	0.1	0.1	0
Total	21.7	15.8	+37
Highly sleep disturbed:			
Road traffic	4.5	5.8	-23
Railway	1.6	0.46	+252
Aircraft	0.23.	0.24	-1
Industry	0.03	0.03	0
Total	6.4	6.6	-3

Table 3-6 indicates that for annoyance the update in exposure-response relation for road traffic noise has the largest absolute effect (additional 4 million adults being annoyed. The update for railways noise leads to the largest relative change (+206%). This is also the case for sleep disturbance (+250%). The biggest absolute change in sleep disturbance is for road traffic noise, but now the prevalence decreases (minus 1.3 million adults). For industry noise the same relations were applied, so there are no change.

Table 3-7 **Effect of the update of the exposure-response relations for the incidence of cardiovascular diseases (IHD and stroke) disturbed according to the noise source, based on the reported and gap filled END data for 2012 (EU28, Iceland, Liechtenstein, Norway and Switzerland)**

Noise source	Case per year (*1,000)		Change (%)
	"new" relation(s)	"old" relation(s)	
IHD incidence only			
Road traffic	41.5	34.4	+20
Railway	6.0	5.1	+16
Aircraft	1.0	1.0	+3
Industry	0.2	0.2	+5
Total	48.7	40.8	+19
IHD and stroke incidence			
Road traffic	41.5	48.7	-15
Railway	6.0	7.3	-18
Aircraft	1.0	1.4	-26
Industry	0.2	0.3	-29
Total	48.7	57.7	-16

At the time of the Noise in Europe 2014 report good quality baseline data on cardiovascular disease and mortality in Europe was limited. For example incidence data was not available, so hospital admissions were used instead. Since the baseline disease and mortality data was also updated for this report the results of 2012 should not be compared with earlier reported results.

For all noise sources the same exposure-response relations were used. The differences in change between the sources in Table 3-7 reflect that not only the relation itself is relevant, but also the underlying noise exposure distribution has an effect when the relation is changed.

For the IHD incidence (upper part of Table 3-7), there is an increase in the number of cases per year for all sources related to the update of the exposure-response relation. The changes are the largest for road traffic and the smallest for aircraft and industry noise. The “old” and “new” exposure-response relation intersect at about 59 dB (see Figure 2-4) which explains the large differences between sources: the impact of the noise sources with a population average L_{den} of about 59 dB (aircraft and industry noise) hardly change.

In this report the health impact assessment is restricted to IHD. In the bottom part of the table, we added the impact of stroke in the column “old” relation, since both diseases were quantified in the Noise in Europe 2014 report. The results indicate that the overall cardiovascular disease incidence is 16% lower when the application of exposure-response relations is restricted to IHD.

In Table 3-8 the comparison is made for mortality, similar to Table 3-7.

Table 3-8 Effect of the update of the exposure-response relations for the mortality due to cardiovascular diseases (IHD and stroke) disturbed according to the noise source, based on the reported and gap filled END data for 2012 (EU28, Iceland, Liechtenstein, Norway and Switzerland)

Noise source	Case per year (*1,000)		Change (%)
	“new” relation(s)	“old” relation(s)	
IHD mortality only			
Road traffic	10.3	13.4	-23
Railway	1.6	2.1	-26
Aircraft	0.2	0.4	-34
Industry	0.1	0.1	-33
Total	12.2	16.0	-24
IHD and stroke mortality			
Road traffic	10.3	18.2	-43
Railway	1.6	2.8	-43
Aircraft	0.2	0.5	-51
Industry	0.1	0.1	-53
Total	12.2	21.6	-43

Again, the same exposure-response relation for IHD was applied for all sources. The relative risk in the “old” and “new” exposure-response relation is the same, but the starting noise level of the relation differs (old 50 and new 53 dB L_{den}). This shift in starting value to a lower noise level results in an impact that is about a quarter less (upper part of Table 3-8).
The exclusion of the stroke results in a further decrease in the estimation of the cardiovascular mortality attributed to environmental noise (overall effect minus 43%, see lower part of table).

The exposure-response relation for reading impairment in relation to aircraft noise remained unchanged.

3.5 Estimation of potential double counting

In section 2.5.2 we described the procedure to estimate the possible double counts in the calculated impact due to exposure to multiple noise sources.

In Table 3-9, the results of the estimation of potential double counting in the impact of the reported numbers for highly annoyed and highly sleep disturbed adults are shown.

Table 3-9 **Estimation of double counts for highly annoyed and highly sleep disturbed, based on the reported and gap filled END data for 2012 (EU28, Iceland, Liechtenstein, Norway and Switzerland)**

Noise source	Impact among adults (*1,000,000)	
	Highly annoyed	Highly sleep disturbed
Added impact all sources and locations	21.7	6.4
Added impact all sources in major agglomerations	15.3	4.3
- Related to road traffic noise	12.5 (82%)	3.3 (75%)
- Related to other sources of noise	2.8 (18%)	1.0 (25%)
Added impact all major sources	6.5	2.0
Combined impact all major sources and road traffic related in major agglomerations	19.0 (87%)	5.3 (84%)

The first line in Table 3-9 describes the total impact if we add the numbers of the individual assessment for the different noise sources and locations of the assessment areas. For highly annoyed, the added impact is 21.7 million adults.

We assume, as described in section 2.5.2 that the burden of highly annoyed due to road traffic noise (12.5 million) is the minimum estimate for the total noise annoyance in the major agglomerations. We also assume that the impact in the assessment areas of the major sources is independent of each other (total 6.5 million for highly annoyed). The impact of road traffic noise within the major agglomerations and in the assessment areas of the major sources can be added up since these locations are spatially independent. For highly annoyance, this leads to 19.0 million adults. As indicated, this total is a minimum estimation. The double count is estimated to be not more than 2.7 of the 21.7 million (maximum 13%) projected cases of being highly annoyed by environmental noise.

For sleep disturbance, we expect that the double counts are not more than 1.1 of the 6.4 million cases projected (maximum 16%).

Like described above, we expect that the burden of disease due to IHD in the assessment areas of the major sources can be combined without a risk of double counting. Since the assessment areas are hotspot, we assume that other noise sources than the source of concern have exposure levels which do lead to additional risks for IHD.

Table 3-10 reports the results of the estimation of potential double counting in the impact of the reported numbers for IHD incidence and premature mortality in the major agglomerations.

Table 3-10 **Estimation of double counts for incidence and premature mortality due to ischaemic heart diseases, based on the reported and gap filled END data for 2012 (EU28, Iceland, Liechtenstein, Norway and Switzerland)**

Source in major agglomeration	Incidence		Premature mortality	
	PAF	Cases per year	PAF	Cases per year
Road traffic	0.032450	30,040	0.021815	7,550
Railway	0.003469	3,210	0.002490	860
Aircraft	0.000872	810	0.000560	190
Industry	0.000248	230	0.000177	60
PAFs added up (reported)	0.037038	34,280	0.025042	8,670
Combined PAF	0.036885	34,140	0.024969	8,650
Double counts		~140		~20

In the first four lines the population attributable fraction (PAF) of the individual assessments for the four noise sources and their impact on incidence and mortality are shown. The PAFs in the table are for the total agglomeration, and not for the assessment areas. In the fifth line, the impact is added up. The combined impact is 34,280 incidence case of IHD per year.
To assess the joint impact of multiple noise sources, we calculated a combined PAF from the PAFs of the individual sources: the related impact is 34,140 incidence case of IHD per year.
The estimated double counting for the incidence of IHD is about 140 cases per year. For the premature mortality about 20 cases per year. These numbers are very small in the light of the uncertainties of the calculated impacts.

3.6 Effect of choices in the disability weight for the assessment of burden of disease due to environmental noise

We carried out calculation using different disability for highly annoyed, highly sleep disturbed and reading impairment to assess the sensitivity of the results of a burden of disease assessment for choices in the disability weights. The results of the calculations are given in Table 3-11. We added the results of the burden of disease of IHD due to noise in the table.

Table 3-11 Impact of choices in the assessment of burden of disease due to environmental noise for 2012 (EU28, Iceland, Liechtenstein, Norway and Switzerland)

Health endpoint	Disability weight	DALYs in 2012
Highly annoyed		
21.7 million adults	0 0.01 0.02	0 217,300 (YLD) 434,600 (YLD)
Highly sleep disturbed		
6.4 million adults	0.0175 0.07	111,300 (YLD) 445,000 (YLD)
Reading impairment		
13,300 children	0 0.006	0 80 (YLD)
IHD		
Incidence 48,700 cases/yr Premature mortality 12,200 cases/yr	- -	17,400 (YLD) and 150,200 (YLL)

Our reference is the burden of disease of IHD (total 168 thousand DALYs per year), since this health outcome is the only endpoint from the endpoints listed in Table 3-11 that is part of the most recent Global Burden of Disease study (GBD, 2017).
Application of the methodology used for the EBODE study (Hänninen and Knol, 2011) (including IHD and sleep disturbance and excluding annoyance and reading impairment) and using the updated disability weight for sleep disturbance in the guidance document (van Kamp et al., 2018) results in a burden of disease of 280 thousand DALYs per year.
If both annoyance and sleep disturbance are included in the assessment and the disability weights of the guidance document are used and reading impairment is excluded, the total burden becomes about 500 thousand DALYs per year.
Including all endpoints and applying the disability weights indicated in WHO Burden of disease from environmental noise report (WHO, 2011) results in a total burden of 1,050 thousand DALYs for 2012.

4 Discussion

The two main objectives of this study were:

- To carry out a health impact assessment using recent reported END data and updated exposure-response curves, to provide key results for various health endpoints and to document the the applied methodology.
- To carry out additional analyses to evaluate the effects of changes in the methodology and to assess the sensitivity of the results for choices in the assessment;

In the chapter, we will discuss only the methodology of the health impact assessment.

4.1 Population noise exposure using END data

We used reported END data provided by the EU28, Iceland, Liechtenstein, Norway and Switzerland for the second and third round of noise mapping in the framework of the END. The completeness of the 2012 data was almost 90% for the major agglomerations and about 95% for the major sources. The missing data was imputed using a gap filling routine. Given the level of completeness, the results obtained with the health impact assessment will be very close to the findings that would have been reported if all END data would have been provided. The 2017 is still far from complete (about 50%). The findings reported on 2017, although also imputed, will be subject to changes when more data becomes available. For this reason, we based the additional analyses in this report on the 2012 dataset.

To estimate an average exposure level for the 5 dB categories of the END data, we refined the data to 1 dB first. It was essential for the applied refinement method that we supplemented the reported and gap filled END data first with population numbers for the categories below 55 dB L_{den} and below 50 dB L_{night}, the lowest levels of the END assessment areas. The data added was only used for the refinement and did not change the population in the 5 dB categories above 55 dB L_{den} or 50 dB L_{night}. Also, these added populations were not included in the health impact assessment.
Tables 2-4 to 2-5 on the population in lower exposure categories near major sources show that the population per 5 dB increases with decreasing noise categories. This phenome is caused by the logarithmic nature of noise attenuation among its transmission path (European Community 2015). Road traffic noise within agglomerations was supplemented differently (Table 2-3), since the lower exposure categories are mainly caused by traffic movements on the underlying road network (European Commission WG-AEN, 2007).
The average exposure levels in the exposure categories do not differ substantially from the midpoint value of the category. We expect no large influence on the findings of the health impact assessment if we had used the midpoint values.

Health impact assessments based of END data have two important limitations. First, such an impact assessment is based on two different noise assessments (L_{den} for annoyance, reading impairment, and IHD, and L_{night} for sleep disturbance). Since not completely the same population is included in the L_{den} and in the L_{night} assessment areas, it is not clear to which population the health impact refers. And in the case that the assessment area with a lower level of 55 dB L_{den} fully includes the assessment area with a lower level of 50 dB L_{night}, sleep disturbance among residents living between 50 dB L_{den} and 55 dB L_{night} will be ignored. It is difficult to explain that sleep disturbance is "missed" since the L_{night} is unknown, although the L_{den} (including the L_{night}) has been assessed. Second, the health risk due to noise exposure occurs also below the lower levels of the assessment area for L_{den} and L_{night}. The burden of disease in major agglomerations and from major sources is therefore underestimated when it is based on END data only.

4.2 Highly annoyed and highly sleep disturbed

It is rather straightforward to implement the updated exposure-response relations of highly annoyed and highly sleep disturbed for road traffic, railway and aircraft noise (Guski et al., 2017 and Basner and McGuire, 2018). Unfortunately, no new information was available for industry noise. We used an exposure-response relation for annoyance that was reported 15 years ago for industrial sites in one country only (Miedema and Vos, 2004). For highly sleep disturbance no exposure-response relation is available for industry noise. An estimation of the noise induced sleep disturbance due to industry in the major agglomeration was derived using the road-annoyance relationships described in Miedema and Vos (2007). Therefore, the results for annoyance and sleep disturbance from industry noise should be seen as indicative.

In the papers of Guski et al. (2017) and Basner and McGuire (2018) it is indicated that there is substantial variation in the results of the underlying studies. For local health impact assessment it is therefore important to consider whether the updated exposure-response relations are representative for the specific situation and to explore if local and/or national derived relations are available and suitable for use.

The updated exposure response relation for high annoyance leads to a 40 percent increase in the total burden of annoyance. Road traffic noise contributes the most when the increase is expressed in number of cases. However, it should be noted that the burden of annoyance due to railway noise triples. The relative increase is even larger for sleep disturbance due to railway noise. The total burden of sleep disturbance of sleep disturbance is not affected by the update, since the burden due to road traffic noise lessens. These results reflect that the update of the relations can have important consequences for the prioritisation of noise sources in action plans.

The use of END data may potentially lead to double counts in the burden of annoyance and sleep disturbance in locations where there is exposure from multiple noise sources. We have described in Chapter 2 and 3 why we expect that double counting is not an important issue in the assessment areas of the major sources. We have also reasoned that the burden of annoyance due to road traffic noise is a conservative estimate for the total burden of annoyance in the major agglomerations. Based on these assumptions, we have calculated that the double counts will be less than 13% for highly annoyed, and less than 16% for highly sleep disturbed. Given all other uncertainties in the estimation of the burden, we see no reason to adjust the total numbers of highly annoyed and highly sleep disturbed that we report as summation of the burden due to the four noise sources based on the individual assessments in major agglomeration and around major sources.

4.3 Reading impairment

There is no consensus about an exposure-response relation for reading and/or cognitive impairment. For a health impact assessment, a method is necessary that leads to a number of inhabitants affected. Reading and/ cognitive endpoints are usually measured on a continuous scale, so study results are not directly useable to obtain an exposure-response relation. We transformed the results of the RANCH study into a new relation. Unfortunately, we could not include for this report the results of other studies, like from the NORAH study (Klatte, et al., 2017) since for the transformation the original study data is required. Therefore, the transferability of exposure-response relation remains unclear. Also, the RANCH study did not find a threshold level for the effects on reading performance. We introduced a starting value of 50 dB L_{den} in the new relation which might have led to an underestimation of the burden. The burden of reading impairment is relative small in comparison with the other endpoints. The reasons are that it is assumed that the population at risk consist only of children on primary and secondary schools and that the risk relates to aircraft noise only. Little is known about the consequence in later life of delay in reading at younger age.

The burden due to reading impairment was quantified in the Noise in Europe 2014 report. Given the limitations above, we recommend EEA to consider whether the burden of reading impairment should be part of a new Noise in Europe publication or a similar report. An important reason for inclusion is that reading impairment reflects that effects of noise also take place at young age and that WHO considered cognitive impairment as a critical health outcome.

4.4 Ischaemic heart disease

The number of studies with at least moderate quality on the association between noise exposure and the incidence and mortality is small and limited to road traffic and aircraft noise only. There is no evidence that the relative risks differs between noise sources. Also it is biological plausible that both incidence and mortality due to IHD are related to noise exposure. We made the choice to use the results from the studies with the highest quality (road traffic noise) also for other sources to ensure that the burden of IHD incidence and premature mortality can be estimated for all noise sources. We are less strict in the selection of study results than was done by the GDG to derive guideline noise values for individual sources. We are confident that the burden of IHD is underestimated and choices about priorities between sources cannot be made adequately when the risks of other noise sources than road traffic and aircraft are ignored and IHD is limited to incidence only. The key findings for 2012 and 2017 indicate that the contribution of YLL (based on mortality) to the burden of disease of IHD is almost 9 times larger than the contribution of YLD (based on incidence). Expressing the mortality in years of life lost is preferred above the number of premature deaths, since death is only postponed when the exposure is reduced (Brunekreef et al., 2007).

The implementation of the methodology of IHD is less straightforward than the implementation of annoyance and sleep disturbance. Information on baseline incidence and mortality rates have to be collected and a measure from the public health domain (population attributable fraction) is necessary to carry out the calculations. It is advised to collaborate with a public health institute when local or national health impact assessments are carried out so the quality of the outcomes and a correct interpretation of the results are assured.

We have quantified the potential double counts where there is exposure from multiple noise sources. The results indicate that potential double counts are no issue for IHD (less than 1%).

4.5 Burden of disease

Disability weights are normative parameters. They are subjective interpretations of a number for which no true value exists. It is recommended that the same set of disability weights is used globally to assure comparability between the obtained YLDs. Over the years, methodological improvements have been made in the assessment of disability weights like the composition of the panel, health state description, time presentation and valuation methods, so it is preferred to use results from recent valuation studies for disability weights. It is therefore recommended to use the disability weights proposed in the guidance document (van Kamp et al., 2018) if one would like to include the impact of annoyance and/or sleep disturbance in a burden of disease study.

The guidance document indicates whether highly annoyed and/or highly sleep disturbed should be part of a health impact assessment depends on the scope of the assessment and the perspective from which one considers noise and health. One should be aware that, if these endpoints are included, the resulting burden of disease cannot necessarily be compared with the burden of disease assessed in other studies.

For example, the most recent Global Burden of Disease study (GBD 2017) did not include high annoyance nor high sleep disturbance.

The results in section 3.6 and in Table 3-11 illustrate that the choices about the inclusion of annoyance and/or sleep disturbance in a health impact assessment and of the value of the disability weight for these endpoints have large consequences for the projected burden of disease due to noise expressed in DALYs. There is a 6-fold difference between the estimation based on the health endpoint considered in Global Burden of Disease studies (IHD: 168 thousand DALYs per year) and the estimation based on highly annoyed, highly sleep disturbed and reading impairment using the (ingrained but out-of-date) disability weights of WHO (2011) and on IHD (in total one million DALYs per year).

We recommend EEA to report the health implication of environmental noise in number of adults being highly annoyed or highly sleep disturbed, number of children with reading impairment, number of cases IHD incidence per year and the combination of premature mortality per year and the years of life lost if the publication is on environmental noise only, given the large consequence of choices made about the endpoints included in burden of disease calculations.

5 Conclusions

The health implications of environmental noise in the 32 countries included in this assessment can be described as the number of adults being highly annoyed and highly sleep disturbed, the number of children with reading impairment attributable to aircraft noise, the number of new cases each year (incidence) of ischaemic heart disease and the number of premature deaths each year and the years of life lost due to ischeamic heart disease.
We discourage the use of burden of disease calculations expressed as DALYs per year, when the publication is on environmental noise only.

Based on the reported and gap filled data of the second round of noise mapping (update September 2018), it is estimated that 21.7 million adults are highly annoyed due to noise from road traffic, railways, aircrafts or industry. 6.4 Million adults are expect to suffer from noise related sleep disturbance. Environmental noise exposure contributed to 49 thousand incidence cases each year of ischaemic heart disease and to 12 thousand cases of premature mortality each year which leads to about 150 thousand years of life lost. About three quarter of the health impact is related to road traffic noise exposure.

The findings may include double counts due to multiple exposure to noise sources. The number of double counts is unknown, but it is expected that the double counts are less than 13% of the reported numbers for annoyance, less than 16% for sleep disturbance and less than 1% for incidence and mortality due to ischaemic heart disease.

The update of the exposure-response relations leads to an increase in the total burden of highly annoyed. The total burden of highly sleep disturbance is not affected, but there are substantial differences between noise sources. The relative changes are the most prominent for railway noise.

The completeness of reported data for the third round is about 50%. Primary analyses indicate that the burden of disease of noise related health endpoints in 2017 is similar to the findings for 2012.

References

Alberts W, N Faber, M Roebben (2016) Road traffic noise in Europe in 2012 based on END data. In: Proceedings of the INTER-NOISE 2016. 45th International Congress and Exposition on Noise Control Engineering. Towards a Quieter Future. Hamburg, Germany.

ANOTEC Consulting S.L. (2003) Study on Current and Future Aircraft Noise Exposure at and around Community Airports – Final Report. Doc. no. PAN012-4-0. Motril, Spain.

Basner M, McGuire S (2018) WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Effects on Sleep. Int. J. Environ. Res. Public Health 15(3), 519; https://doi.org/10.3390/ijerph15030519.

Brown A, van Kamp I (2017) WHO Environmental Noise Guidelines for the European Region: A Systematic Review of Transport Noise Interventions and Their Impacts on Health. Int. J. Environ. Res. Public Health 14(8), 873; https://doi.org/10.3390/ijerph14080873.

Brunekreef B, Miller BG, Hurley JF (2007). The brave new world of lives sacrificed and saved, deaths attributed and avoided. Epidemiology 18: 785-8.

Clark C, Martin R, Van Kempen E, Alfred T, Head J, Davies HW, Haines MM, Barrio IL, Matheson M, Stansfeld SA (2006) Exposure-effect relations between aircraft and road traffic noise exposure at school and reading comprehension: The RANCH project. American Journal of Epidemiology 163 (1), pp. 27-37.

Clark C, Paunovic K (2018) WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Cognition. Int. J. Environ. Res. Public Health 15(2), 285; https://doi.org/10.3390/ijerph15020285.

EEA (2010) Good practice guide on noise exposure and potential health effects. Technical report No 11/2010. European Environment Agency. Copenhagen, Denmark.

EEA (2014) Noise in Europe 2014. EEA report 10/2014. European Environment Agency. Copenhagen, Denmark.

Eriksson C, Pershagen G, Nilsson M (2018) Biological mechanisms related to cardiovascular and metabolic effects by environmental noise. WHO Regional Office for Europe. Copenhagen, Denmark.

European Commission (2002) Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise. Official Journal of the European Communities L189 of 18.7.2002, 12–25.

European Commission WG-AEN (Working Group Assessment of Exposure to Noise) (2007) Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure Position Paper. Version 2. August 2007.

European Community (2015) Commission directive (EU) 2015/996 of 19 May 2015 establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council, May 2015.

GBD 2017 Disease and Injury Incidence and Prevalence Collaborators (2017) Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. The Lancet, Vol. 392, No. 10159.

Guski R, Schreckenberg D, Schuemer R (2017) WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Annoyance. Int. J. Environ. Res. Public Health 14(12), 1539; https://doi.org/10.3390/ijerph14121539.

Haagsma JA, de Noordhout CM, Polinder S, Vos T, Havelaar AH, Cassini A, Devleesschauwer B, Kretzschmar ME, Speybroeck N, Salomon JA (2015) Assessing disability weights based on the responses of 30,660 people from four European countries. Population Health Metrics, 13 (1), art. no. 10.

Hänninen O, Knol A editors (2011) European Perspectives on Environmental Burden of Disease: Estimates for Nine Stressors in Six Countries. Report 1/2011. National Institute for Health and Welfare (THL). Helsinki, Finland.

Hänninen O, Knol AB, Jantunen M, Lim T-A, Conrad A, Rappolder M, Carrer P, Fanetti A-C, Kim R, Buekers J, Torfs R, Iavarone I, Classen T, Hornberg C, Mekel OCL (2014) Environmental burden of disease in Europe: Assessing nine risk factors in six countries.Environmental Health Perspectives 122 (5), pp. 439-446.

Houthuijs DJM, AJ van Beek, WJR Swart, EEMM van Kempen, FAAM de Leeuw (2015) Health Impact Assessment for Noise in Europe. Expected consequences of the limitations of the available noise exposure data. ETC/ACM Technical Paper 2014/9. Bilthoven, the Netherlands. https://acm.eionet.europa.eu/reports/ETCACM_TP_2014_9_HIA-noise_europe

Houthuijs DJM, AJ van Beek, WJR Swart, EEMM van Kempen (2014) 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. Bilthoven, the Netherlands.

Houthuijs D, Fons J, Sáinz de la Maza M, Swart W, van Beek A. (2018) Method to estimate the road traffic noise exposure distribution in Europe. ETC/ACM Technical Paper 2017/10. Bilthoven, the Netherlands. https://acm.eionet.europa.eu/reports/ETCACM_TP_2017_10_traffic_noise_exposure_distribution_europe

Houthuijs D, de Leeuw F (2018) Combined health impact assessment of noise and air quality in urban agglomerations. An explorative study. ETC/ACM Technical Paper 2017/12. Bilthoven, the Netherlands. https://acm.eionet.europa.eu/reports/ETCACM_TP_2017_12_HIA_END_aggloms

Janssen SA, H Vos H (2009) A comparison of recent surveys to aircraft noise exposure-response relationships TNO report TNO-034-DTM- 2009-01799. Delft, the Netherlands.

Jarosińska D, Héroux M, Wilkhu P, Creswick J, Verbeek J, Wothge J, Paunović E (2018) Development of the WHO Environmental Noise Guidelines for the European Region: An Introduction. Int. J. Environ. Res. Public Health 15(4), 813; https://doi.org/10.3390/ijerph15040813.

Klatte M, Spilsk J, Mayer J, Möhler U, Lachmann T, Bergström K (2017) Effects of Aircraft Noise on Reading and Quality of Life in Primary School Children in Germany: Results From the NORAH Study. Environment and Behavior, 49: 390-424.

Miedema, HME (2004) Relationship between exposure to multiple noise sources and noise annoyance, J. Acoust, Soc. Am. 116 (2).

Miedema HME, Vos H (2004) Noise annoyance from stationary sources: Relationships with exposure metric day-evening-night level (DENL) and their confidence intervals. Journal of the Acoustical Society of America, 116 (1), pp. 334-343.

Miedema HME, Vos H (2007) Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies. Behavioral Sleep Medicine, 5 (1), pp. 1-20.

Nieuwenhuijsen M, Ristovska G, Dadvand P (2017) WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Adverse Birth Outcomes. Int. J. Environ. Res. Public Health 14(10), 1252; https://doi.org/10.3390/ijerph14101252.

PBL (2009) Modelling local environmental quality and its impact on health, Netherlands Environmental Assessment Agency (PBL). Bilthoven, The Netherlands.

Pierrette M, Marquis-Favre C., Morel J, Rioux L, Vallet M, Viollon S, Moch A (2012) Noise annoyance from industrial and road traffic combined noises: a survey and a total annoyance model comparison. J. Environ. Psychol. 32 (2), 178–186.

Śliwińska-Kowalska M, Zaborowski K (2017) WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Permanent Hearing Loss and Tinnitus. Int. J. Environ. Res. Public Health 14(10), 1139; https://doi.org/10.3390/ijerph14101139.

Van den Hout D, Salomons E, Polinder H, Janssen S, Graham J, Vojtech M, Kuusisto E (2011) HEIMTSA. Health and Environment Integrated Methodology and Toolbox for Scenario Development. Sixth Framework Programme Thematic Priority 6.3. D 7.1.9 Integrated Environmental Health Impact Assessment for noise due to urban road traffic.

Van Kamp I, Schreckenberg D, van Kempen EEMM, Basner M, Brown AL, Clark C, Houthuijs DJM, Breugelmans ORP, van Beek AJ, Janssen-Stelder BM (2018) Study on methodology to Perform environmental noise And health assessment. RIVM Report 2018-0121. Bilthoven, The Netherlands.

Van Kempen EEMM (2008) Transportation noise exposure and children's health and cognition. Thesis Utrecht University. Utrecht, the Netherlands.

Van Kempen E, Casas M, Pershagen G, Foraster M (2018) WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Cardiovascular and Metabolic Effects: A Summary. Int. J. Environ. Res. Public Health 15(2), 379; https://doi.org/10.3390/ijerph15020379.

Vienneau D, Perez L, Schindler C, Probst-Hensch N, Röösli M (2013) The relationship between traffic noise exposure and ischemic heart disease: a meta-analysis (2013) In: Proceedings of INTER-NOISE 2013, the 42nd International Congress and Exposition on Noise Control Engineering. Innsbruck, Austria.

Vienneau D, Schindler C, Perez L, Probst-Hensch N, Röösli M (2015) The relationship between transportation noise exposure and ischemic heart disease: A meta-analysis. Environmental Research, 138, pp. 372-380.

WHO (2000) Evaluation and use of epidemiological evidence for environmental health risk assessment. Guideline document. WHO Regional Office for Europe. Copenhagen, Denmark.

WHO (2004). Global Burden of Disease 2004 Update: Disability weights for diseases and conditions. World Health Organization. Geneva, Switzerland.

WHO (2009). Night noise guidelines for Europe. WHO Regional Office for Europe. Copenhagen, Denmark.

WHO (2011) Burden of disease from environmental noise. Quantification of healthy life years lost in Europe. World Health Organization Regional Office for Europe. Copenhagen, Denmark.

WHO (2012) Methodological guidance for estimating the burden of disease from environmental noise. World Health Organization Regional Office for Europe. Copenhagen, Denmark.

WHO (2018) Environmental Noise Guidelines for the European Region. WHO Regional Office for Europe. Copenhagen, Denmark.

Annex 1 – Fractions used for L_{den} of road traffic noise in major agglomerations

Fraction from population above 55 dB L_{den} to estimate the population in lower 5 dB exposure category for road traffic noise within agglomerations in 31 EEA member countries. Liechtenstein is missing since it has no agglomeration with more than 100,000 inhabitants.

For the fractions applied in the other countries, we refer to section 2.2.2. For the explanation of the ISO code, see Annex 3.

ISO code	Fraction 25 – 29 dB	Fraction 30 – 34 dB	Fraction 35 – 39 dB	Fraction 40 – 44 dB	Fraction 45 – 49 dB	Fraction 50 – 54 dB
AT	0.001342	0.003916	0.015725	0.063988	0.260885	0.654145
BE	0.001432	0.004183	0.016730	0.067260	0.265214	0.645180
BG	0.001177	0.003435	0.013846	0.057102	0.244889	0.679551
CH	0.001284	0.003751	0.015140	0.061946	0.260698	0.657181
CY	0.002088	0.006159	0.025084	0.096767	0.354358	0.515545
CZ	0.001489	0.004364	0.017755	0.071739	0.292575	0.612078
DE	0.001425	0.004170	0.016857	0.068123	0.278499	0.630928
DK	0.001610	0.004728	0.019209	0.076541	0.301417	0.596494
EE	0.001332	0.003898	0.015814	0.064491	0.271124	0.643341
EL	0.001251	0.003645	0.014566	0.059559	0.243138	0.677841
ES	0.001422	0.004146	0.016478	0.066243	0.254400	0.657311
FI	0.001468	0.004304	0.017498	0.070589	0.288869	0.617272
FR	0.001451	0.004250	0.017245	0.069800	0.284199	0.623056
HR	0.001353	0.003964	0.016147	0.065827	0.276326	0.636384
HU	0.001451	0.004252	0.017252	0.069745	0.286228	0.621071
IE	0.001334	0.003900	0.015760	0.064279	0.268310	0.646416
IS	0.001387	0.004071	0.016716	0.068391	0.293790	0.615645
IT	0.001478	0.004323	0.017381	0.069610	0.273934	0.633275
LT	0.001468	0.004301	0.017443	0.070241	0.282463	0.624084
LU	0.00115	0.003354	0.013553	0.056359	0.248357	0.677227
LV	0.001514	0.004442	0.018108	0.072884	0.295542	0.607511
MT	0.001261	0.003679	0.014758	0.060384	0.252273	0.667645
NL	0.001337	0.003908	0.015815	0.064549	0.270775	0.643617
NO	0.001536	0.004508	0.018349	0.073722	0.297547	0.604338
PL	0.001419	0.004156	0.016877	0.068344	0.281698	0.627507
PT	0.001344	0.003916	0.015544	0.062804	0.246713	0.669679
RO	0.001350	0.003941	0.015778	0.063832	0.256685	0.658413
SE	0.001656	0.004866	0.019833	0.078786	0.306402	0.588457
SI	0.001416	0.004148	0.016798	0.067737	0.277322	0.632579
SK	0.001584	0.004652	0.019014	0.076450	0.306047	0.592253
UK	0.001394	0.004074	0.016409	0.066444	0.271530	0.640149

Annex 2 – Fractions used for L_{night} of road traffic noise in major agglomerations

Fraction from population above 50 dB L_{night} to estimate the population in lower 5 dB exposure category for road traffic noise within agglomerations in 31 EEA member countries. Liechtenstein is missing since it has no agglomeration with more than 100,000 inhabitants.

For the fractions applied in the other countries, we refer to section 2.2.2. For the explanation of the ISO code, see Annex 3.

ISO code	Fraction 25 – 29 dB	Fraction 30 – 34 dB	Fraction 35 – 39 dB	Fraction 40 – 44 dB	Fraction 45 – 49 dB
AT	0.007424	0.027485	0.127368	0.350639	0.487085
BE	0.008036	0.029548	0.132636	0.354183	0.475597
BG	0.006215	0.023104	0.111736	0.340635	0.518310
CH	0.007253	0.026912	0.129207	0.360050	0.476579
CY	0.015229	0.056268	0.243336	0.406928	0.278240
CZ	0.009319	0.034735	0.164259	0.384039	0.407648
DE	0.008599	0.031837	0.149939	0.377951	0.431674
DK	0.010259	0.038105	0.174140	0.385200	0.392296
EE	0.007814	0.029077	0.140375	0.369646	0.453088
EL	0.006275	0.023244	0.106243	0.320486	0.543753
ES	0.007467	0.027440	0.118613	0.332258	0.514222
FI	0.009168	0.034092	0.161490	0.385600	0.409651
FR	0.008680	0.032350	0.151849	0.368954	0.438168
HR	0.008055	0.030103	0.145390	0.372088	0.444364
HU	0.008970	0.033317	0.158219	0.383204	0.416291
IE	0.007889	0.029262	0.139985	0.375211	0.447653
IS	0.008913	0.033479	0.167651	0.395313	0.394645
IT	0.008556	0.031561	0.142035	0.361768	0.456080
LT	0.008704	0.032408	0.149727	0.365750	0.443412
LU	0.006472	0.024077	0.120487	0.365855	0.483109
LV	0.009512	0.035507	0.166823	0.382995	0.405164
MT	0.007053	0.026031	0.123304	0.361260	0.482351
NL	0.007959	0.029541	0.142377	0.376853	0.443271
NO	0.009736	0.036262	0.169872	0.385903	0.398227
PL	0.008644	0.032152	0.152880	0.379392	0.426932
PT	0.007054	0.025856	0.114010	0.337499	0.515582
RO	0.007391	0.027239	0.124028	0.348914	0.492428
SE	0.010589	0.039467	0.177881	0.381533	0.390530
SI	0.008478	0.031417	0.147920	0.374699	0.437486
SK	0.010256	0.038421	0.178915	0.388492	0.383917
UK	0.008284	0.030582	0.143441	0.375922	0.441771

Annex 3 – List of countries

This Annex provides a list of abbreviation for the EEA member countries.

Country name	ISO code
Austria	AT
Belgium	BE
Bulgaria	BG
Croatia	HR
Cyprus	CY
Czech Republic	CZ
Denmark	DK
Estonia	EE
Finland	FI
France	FR
Germany	DE
Greece	EL
Hungary	HU
Iceland	IS
Ireland	IE
Italy	IT
Latvia	LV
Liechtenstein	LI
Lithuania	LT
Luxembourg	LU
Malta	MT
Netherlands	NL
Norway	NO
Poland	PL
Portugal	PT
Romania	RO
Slovakia	SK
Slovenia	SI
Spain	ES
Sweden	SE
Switzerland	CH
Turkey	TR
United Kingdom	UK

Annex 4 – Demographic, disease and mortality data used for 2012

The disease and mortality data for ischaemic heart disease (IHD) is per person per year (pp py).

ISO code	Fraction 7-17 years old	Fraction adults	Incidence rate of IHD pp py	Mortality rate of IHD pp py	YLD for IHD pp py	YLL for IHD pp py
AT	0.10194	0.82052	0.00374	0.00235	0.00183	0.02569
BE	0.11073	0.79633	0.00628	0.00152	0.00179	0.01818
BG	0.08621	0.83876	0.00817	0.00495	0.00279	0.07272
CH	0.10257	0.81682	0.00354	0.00158	0.00143	0.01642
CY	0.11338	0.79429	0.00284	0.00161	0.00144	0.02168
CZ	0.08819	0.82517	0.00638	0.00324	0.00283	0.04198
DE	0.09464	0.83638	0.00491	0.00245	0.00191	0.02808
DK	0.12145	0.78456	0.00396	0.00139	0.00166	0.01619
EE	0.09358	0.81598	0.00816	0.00390	0.00236	0.04880
EL	0.09680	0.82366	0.00516	0.00279	0.00203	0.03504
ES	0.09535	0.82149	0.00367	0.00125	0.00134	0.01469
FI	0.10984	0.79972	0.00461	0.00230	0.00211	0.02796
FR	0.12357	0.77797	0.00373	0.00115	0.00125	0.01282
HR	0.10485	0.81451	0.00608	0.00347	0.00275	0.04559
HU	0.10023	0.82039	0.00725	0.00377	0.00281	0.05219
IE	0.13292	0.74831	0.00320	0.00125	0.00125	0.01655
IS	0.13442	0.75013	0.00434	0.00134	0.00140	0.01545
IT	0.09371	0.83167	0.00565	0.00182	0.00177	0.01940
LI	0.11021	0.80713	0.00364	0.00197	0.00163	0.02106
LT	0.10468	0.81480	0.00798	0.00515	0.00296	0.06970
LU	0.11685	0.79219	0.00269	0.00123	0.00158	0.01478
LV	0.09013	0.82808	0.00742	0.00484	0.00237	0.06860
MT	0.10491	0.81624	0.00402	0.00209	0.00192	0.02787
NL	0.11916	0.79159	0.00503	0.00111	0.00151	0.01417
NO	0.12456	0.77572	0.00319	0.00156	0.00170	0.01720
PL	0.10047	0.81393	0.00612	0.00280	0.00272	0.03853
PT	0.10401	0.81957	0.00338	0.00140	0.00145	0.01641
RO	0.10696	0.80884	0.00664	0.00350	0.00268	0.05003
SE	0.10693	0.79761	0.00545	0.00218	0.00229	0.02305
SI	0.09030	0.82813	0.00499	0.00180	0.00248	0.02134
SK	0.10271	0.81148	0.00563	0.00345	0.00255	0.04775
TR	0.17046	0.69609	0.00387	0.00087	0.00117	0.01551
UK	0.11411	0.78762	0.00598	0.00141	0.00158	0.01847

Annex 5 – Demographic, disease and mortality data used for 2017

The disease and mortality data for ischaemic heart disease (IHD) is per person per year (pp py).

ISO code	Fraction 7-17 years old	Fraction adults	Incidence rate of IHD pp py	Mortality rate of IHD pp py	YLD for IHD pp py	YLL for IHD pp py
AT	0.09613	0.82613	0.00375	0.00239	0.00191	0.02481
BE	0.11282	0.79697	0.00590	0.00154	0.00182	0.01744
BG	0.09288	0.83181	0.00781	0.00533	0.00297	0.07328
CH	0.09774	0.82067	0.00351	0.00156	0.00151	0.01571
CY	0.10706	0.80344	0.00284	0.00169	0.00145	0.02192
CZ	0.09888	0.81841	0.00624	0.00320	0.00303	0.03886
DE	0.09026	0.83677	0.00469	0.00254	0.00203	0.02813
DK	0.11713	0.79679	0.00408	0.00133	0.00171	0.01510
EE	0.10443	0.81015	0.00830	0.00423	0.00255	0.04861
EL	0.10029	0.82556	0.00566	0.00317	0.00224	0.03636
ES	0.10336	0.82038	0.00378	0.00131	0.00143	0.01438
FI	0.10905	0.80523	0.00467	0.00219	0.00221	0.02497
FR	0.12595	0.77886	0.00387	0.00120	0.00142	0.01259
HR	0.09874	0.82389	0.00622	0.00378	0.00292	0.04591
HU	0.09977	0.82507	0.00709	0.00392	0.00293	0.05197
IE	0.13841	0.75043	0.00336	0.00134	0.00137	0.01711
IS	0.13183	0.76420	0.00464	0.00140	0.00150	0.01554
IT	0.09457	0.83643	0.00591	0.00197	0.00183	0.01985
LI	0.10196	0.81910	0.00363	0.00197	0.00171	0.02026
LT	0.09461	0.82078	0.00822	0.00542	0.00322	0.06748
LU	0.10853	0.80415	0.00289	0.00121	0.00156	0.01390
LV	0.09989	0.81718	0.00750	0.00516	0.00266	0.06752
MT	0.09180	0.82963	0.00456	0.00208	0.00210	0.02723
NL	0.11454	0.80071	0.00524	0.00110	0.00163	0.01337
NO	0.12047	0.78490	0.00289	0.00142	0.00169	0.01537
PL	0.09971	0.81972	0.00618	0.00290	0.00283	0.03680
PT	0.10111	0.82733	0.00347	0.00149	0.00156	0.01677
RO	0.10791	0.81155	0.00636	0.00379	0.00283	0.05094
SE	0.11320	0.79226	0.00504	0.00205	0.00244	0.02170
SI	0.09471	0.82368	0.00539	0.00200	0.00264	0.02155
SK	0.09982	0.81554	0.00543	0.00345	0.00272	0.04534
TR	0.15796	0.71320	0.00423	0.00097	0.00130	0.01585
UK	0.11428	0.78863	0.00570	0.00140	0.00161	0.01793

European Topic Centre on Air Pollution
and Climate Change Mitigation
PO Box 1
3720 BA Bilthoven
The Netherlands
Tel.: +31 30 274 8562
Fax: +31 30 274 4433
Web: http://acm.eionet.europa.eu
Email: etcacm@rivm.nl

The European Topic Centre on Air Pollution and Climate Change Mitigation (ETC/ACM) is a consortium of European institutes under contract of the European Environment Agency.

European Environment Agency
European Topic Centre on Air Pollution and Climate Change Mitigation