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and the Environment
Ministry of Health, Welfare and Sport

Study on methodology to Perform environmental noise And health assessment

RIVM Report 2018-0121

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Colofon

DOI 10.21945/RIVM-2018-0121

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Contracting authority:	European Commission, DG Environment, Directorate A, Policy, Coordination and Resources
Contract Number:	070203/SER/2017/771430/ENV.A.3
Title Contract:	“Study on methodology to perform environmental noise and health assessment"
Projectleader:	Brigit Janssen
RIVM-projectnumber:	E/121536/01/AA

Synopsis

Study on methodology to perform an environmental noise and health assessment – a guidance document for local authorities in Europe.

The Environmental Noise Directive (END) is for local authorities the most important instrument to determine the levels of noise pollution. Also, the Directive is aimed at the evaluation of effect of measures and can make the effects of alternative measures visible. The Directive stimulates the Member States to take action to reduce the adverse effects of environmental noise .

Annex III of the Directive is currently under revision and will include a method to calculate the effects of different noise sources, such as road- and rail traffic, according to the latest scientific evidence. In preparation of this update, RIVM in collaboration with international partners has prepared a guidance document. Not only annoyance and sleep disturbance are addressed as health effects, but also cardiovascular effects and cognitive impact in children (comprehensive reading impairment). The document is worded in such a way that it is easily used by local authorities. The guidance document was prepared on request of the EU commission.

The document describes the steps of a health impact assessment one by one and explains the accompanying decisions and conditions. Next, the actual calculation methods are further explained for two indicators: the number of healthy life years adjusted for disease, disability and death (DALY) and the number of people that experiences adverse effects of noise ((NafP). Finally, as an example, the health impact of noise in Düsseldorf is described.

Keywords: noise, health, Environmental Noise Directives, health impact assessment, WHO environmental noise guidelines

Publiekssamenvatting

Onderzoek naar een methode om de gezondheidskundige effecten van geluid te beoordelen – een handreiking voor lokale overheden in Europa.

De Europese richtlijn voor de evaluatie en de beheersing van omgevingslawaai (Environmental Noise Directive, END) is voor lokale overheden het belangrijkste instrument om niveaus van geluidoverlast te bepalen. Tevens is de richtlijn bedoeld om vanuit het gezondheidsperspectief de effecten van maatregelen te evalueren. Ook kan ze de effecten van alternatieve oplossingen inzichtelijk maken. Daarnaast stimuleert de richtlijn dat de lidstaten actie ondernemen om de effecten van geluidsoverlast te beperken.

Annex III van de richtlijn wordt op dit moment aangepast en zal een methode bevatten om de gezondheidseffecten van omgevingsgeluid van verschillende bronnen, zoals weg- en treinverkeer, volgens de nieuwste inzichten te berekenen. Als voorbereiding op deze update heeft het RIVM in samenwerking met internationale partners een handreiking opgesteld. Hierbij worden niet alleen hinder en slaapverstoring als gezondheidseffecten meegenomen, maar ook hart- en vaatziekten en cognitieve effecten bij kinderen (extra leesachterstand door geluid). Het document is toegankelijk verwoord zodat lokale overheden er eenvoudig gebruik van kunnen maken. De handreiking is opgesteld in opdracht van de EU.

In het document worden de stappen van een gezondheidskundige evaluatie voor omgevingsgeluid (Health Impact Assesment) een voor een beschreven. Daarnaast worden de bijbehorende aannames, beslissingen en eisen uitgelegd. Vervolgens worden voor twee indicatoren de feitelijke rekenmethodes verder toegelicht: het aantal gezonde levensjaren gecorrigeerd voor ziekte, handicap en dood (DALY), en het aantal mensen dat nadelige effecten ondervindt van geluid (NafP). Tot slot wordt als voorbeeld een gezondheidskundige evaluatie van geluid in Düsseldorf beschreven.

Kernwoorden: geluid, gezondheid, Europese geluidsrichtlijn, gezondheidskundige evaluatie, WHO richtlijn geluid

Contents

Executive Summary

Annex III of the European Noise Directive 2002/49/EC (END) is under revision, following the latest scientific evidence of the health effects of noise reviewed for an update of WHO's Community Noise Guidelines (now called Environmental Noise Guidelines for the European Region). In 2010, the European Environmental Agency (EEA) published its "Good practice guide on noise exposure and health effects (GPG)" which intended to assist policy makers, competent authorities, and any other interested party in understanding and fulfilling the requirements of the European Noise Directive. The main aim of the GPG was to provide end users with practical and validated tools to calculate the health impacts of noise in strategic noise studies such as the Noise Action Plans (NAPs) of the Directive. The GPG does not, however, provide guidance on how effects of environmental noise (actions/interventions) on health and well-being of the population can be estimated and used to justify or establish priorities within the NAPs. To fill this gap, the main aim of this project is to develop a guidance tool that can be used to assess and evaluate the (cumulative) health effects at the population level due to environmental noise exposure to complement the noise mapping and to inform on the health benefits of the actions foreseen in the noise action plans performed according to articles 1, 7 and 8 of the Environmental Noise Directive. The assessment of the impact on health and well-being due to risk factors (e.g. noise) and/or (infrastructural) actions/interventions is often done as part of a health impact assessment (HIA).

Specific objectives were

1. To select and evaluate environmental health indicators suitable to apply in the END context;
2. To give insight in what data is needed to calculate the environmental health indicators and to determine the scale level at which they can be applied;
3. To give insight in when and how the different indicators can be used in a health impact assessment for environmental noise;
4. To develop a methodology and guidance tool at least at city level (based on previous);
5. To apply the selected indicators in a case study.

Based on a literature study and expert consultations, five representative health indicators were preselected and described in detail in terms of data needs, expertise needs, uncertainties and calculation method. In a consultation among nineteen experts and stakeholders using three online Delphi rounds, the indicators were evaluated on a set of criteria. These included scientific robustness, ease of use, and understanding and suitability for evaluating changes, e.g. for NAPs. Based on this, Disability Adjusted Life Years (DALY) and number of people affected (NafP) were selected as good examples of environmental health indictors to be used in the HIA, and these two indicators are described in greater detail in this guidance document.

Following the process of a HIA, a description of the types of policy questions underlying an impact assessment is provided, and the suitability of different indicators for these questions are discussed. For some questions, a qualitative analysis of different policy alternatives is sufficient, while in other cases a quantitative estimation of the magnitude of effects and/or ranking of these effects is needed. Once the key decisions are made and all conditions are met, the actual assessment comprises of five key steps: 1) choice of health outcomes; 2) assessment of noise exposure in a given population; 3) selection of exposure response relations; 4) calculating the NafP; and 5) calculation of the actual burden of disease expressed in terms of DALYs.

In line with these steps, this guidance document provides a detailed description of the health outcomes selected based on the latest evidence reviews and gives guidance regarding the inputs needed for a HIA. As an example the usability of the different approaches (DALY and NafP) was tested in two cases in Dusseldorf. The methodology it described is primarily valid at city level.
With a stepwise explanation of the methodology and actual calculations of health impacts of noise, the guidance document hopes to support local authorities to quantify the health impacts of their noise action plans and compare the impact against alternative solutions

Glossary

AF	Attributable fraction
AR	Attributable risk
DALY	disability adjusted life years
DR	dose-response
CI	Confidence interval
CHERIO	Cumulative Health-based Environmental Risk Indicator
CNOSSOS	common noise assessment methods for Europe
DALY	Disability-adjusted life year
DEN	Day-evening-night equivalent level
DW	Disability weight
EBoDe	Environmental Burden of Disease in the European Region
EBD	Environmental Burden of Disease
EEA	European Environment Agency
END	Environmental noise directive (2002/49/EC)
ERF	Exposure Response Function
HIA	Health Impact Assessment
EU	European Union
GBD	Global burden of disease
HA	Highly annoyed people
HES	Health Effect Screening
HSD	Highly sleep disturbed people
ICD-9	International Statistical Classification of Diseases and Related Health Problems, ninth revision
ICD-10	International Statistical Classification of Diseases and Related Health Problems, tenth revision Incidence
Incidence	Measure of the probability of occurrence of a given medical condition in a population within a specific period of time
LAeq,th or Leq,th	A-weighted equivalent sound pressure level over (t) hours
L_{den}	Day-evening-night equivalent sound level
L_{dn}	Day-night equivalent sound level
L_{night}	Night equivalent sound level
Morbidity	the rate of disease in a population.
Mortality	A measure of the number of deaths in a given population
NAP	Noise action plan
NafP	Number of affected people
OR	Odds ratio
PAR	Population attributable risk
PAF	Population attributable fraction
Prevalence	Actual number of cases of disease or injury present in a population at any particular moment in time.
PSG	Polysomnography
REM	Rapid eye movement (sleep stage)
SD	Standard deviation
SMPH	Summary measures of population health
SWS	Slow wave sleep
WHO	World Health Organization
YLD	Years of live lost due to disability
YLL	Years of life lost due to premature mortality

1 Introduction

1.1 Context

Annex III of the Environmental Noise Directive 2002/49/EC (END) will describe a method for calculating the health impacts of exposure to environmental noise levels from different sources. Currently, Annex III is under revision, following the latest scientific evidence of the health effects of noise reviewed for an update of the formerly named Community Noise Guidelines of WHO[1] now referred to as the Environmental Noise Guidelines for the European Region.[1]

In 2010, the European Environmental Agency (EEA) published its "Good practice guide on noise exposure and health effects (GPG)"[2] which intended to assist policy makers, competent authorities and any other interested party in understanding and fulfilling the requirements of the European Noise Directive. The main aim of the GPG was to provide end users with practical and validated tools to calculate the health impacts of noise in strategic noise studies such as the Noise Action Plans (NAPs) of the Directive. It does, however, not provide guidance on how health and well-being effects can be estimated, and used to justify or establish priorities within the NAPs.

The main aim of this project is to develop a guidance tool that can be used to assess and evaluate the (cumulative) health effects at the population level due to environmental noise exposure to complement the noise mapping and to inform on the health benefits of the actions foreseen in the noise action plans performed according to articles 1, 7 and 8 of the Environmental Noise Directive.

This project was based on the following assumptions:

- The WHO reviews prepared in the framework of the new Environmenta Guidelines[7] are taken as a point of departure http://www.mdpi.com/journal/ijerph/special_issues/WHO_reviews.
- Scientific evidence on noise and health published after the timeframe of the reviews is also accounted for.
- The described methodology considers noise sources separately and integrates health effects where relevant.
- The main focus is on adults (18 years and older), but when data is available for specific groups, like children, this can be used as input for the methodology.
- To apply the disability adjusted life years indicator (DALY) and one or more additional environmental health indicators in a case study.
- To preferably express the burden of disease in a single value, so it has added value to the noise maps.
- The methodology to be at least valid at city level (≥100.000 inhabitants).

[1] Although the WHO environmental noise guidelines and their underlying reviews are at the base of this guidance document, the aim of the two document is quite different: while the guidelines primarily focus on threshold levels and limit values, this guidance document looks at the whole range of exposures rather than above a certain level of noise;

1.2 Study design and Method

Specific objectives of the project are:

1. To select and evaluate environmental health indicators suitable to apply in the END context;
2. To give insight in what data is needed to calculate the environmental health indicators and to determine the scale level at which they can be applied;
3. To give insight in when and how the different indicators can be used in a health impact assessment for environmental noise;
4. To develop a methodology and guidance tool at least at city level (based on previous);
5. To apply the selected indicators in a case study.

Practically this implied the following tasks:

1. Task 1: Perform a literature review on environmental health indicators
2. Task 2: Evaluate selected environmental health indicators
3. Task 3: Perform stakeholder consultation
4. Task 4: Choose indicators to be included in the guidance document
5. Task 6: Pilot usability of the selected indicators in a case study
6. Task 5: Develop the methodology and the guidance document

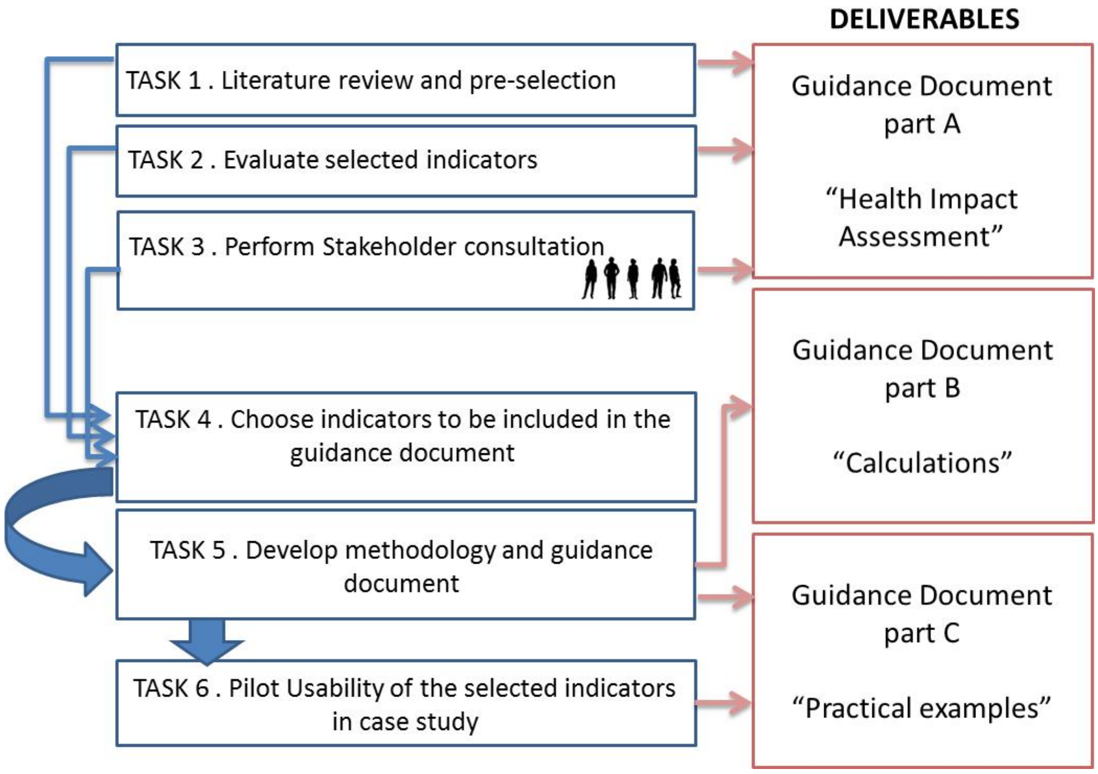

Figure 1.1: Overview of tasks and deliverables

In preparation of the guidance document, a short overview was prepared (Task 1) of example indicators currently available and frequently used in the domain of environment and health, based on the recent scientific and grey literature. These (summary) environmental health indicators can be helpful for (local) authorities working in the domain of environment and health. The application of such indicators is not an aim in itself, but should support the process and the communication between different stakeholders and to help answer the underlying questions. The choice for a particular indicator depends primarily on the question(s) that ha(s)ve to be answered (e.g. priority setting, comparison of the effects of different noise reduction actions) and the phase in the decision making process: policy preparation, decision, implementation, or evaluation of noise reducing actions.

Also, several experts in the field of environment and health were consulted. From the resulting list of identified indicators, first five were selected (Task 1) as good examples of noise and health indicators that can be expressed at municipality/urban level. The key features of these indicators are summarized and the calculation method and data needs are briefly presented per indicator (Task 2).

Next, the five indicators were evaluated in a stakeholder consultation using the Delphi Method, with 19 international stakeholders (response rate 70%) and experts during three rounds (Task 3). In the third round people were asked to score the indicators along eight criteria, which were derived from the literature [3,4,5] (see also Appendix I). Subsequently two indicators: (I) Number of People Affected (NafP) and (II) Disability adjusted life years were selected to be included in the guidance document (Task 4) and piloted in the two cases in Dusseldorf (Chapter 4). DALY's were included firstly as part of the requirements in the assignment by the Commission. Moreover, in the stakeholder consultation the DALY indicator scored high on the *relevance criteria to quantify health effects* of noise and the *sensitivity to change criteria*. This is of particular importance in the END context and the evaluation of the noise action plans (NAP's). The NafP scored particularly high on the criteria related to *simplicity of implementation* and *understandability for the general public*. In that sense the indicators can be considered as complementary.[2]

The usability (Task 6) was tested in two cases in Düsseldorf, which are described in detail in Chapter 4.

1.3 Readers Guide

Chapter 2 is the actual Guidance Document part A, describing the key steps in a Health Impact Assessment (HIA) for noise effects on health, theoretical backgrounds and the process of indicator selection and the main decisions in the HIA process. Chapter 3 is the Guidance Document part B, which provides guidance for the actual calculation. Chapter 4 is the Guidance Document part C, and presents two practical examples of a HIA in Dusseldorf, including the evaluation of noise action plans. Details about the results of the Delphi consultation are presented in Appendix I.

[2] This does not imply that the other three indicators are not useful in a HIA.

2 Guidance Document part A: Health Impact Assessment

2.1 Steps in the HIA process: a model

Figure 2.1 describes the different decisions to be made preceding a HIA as well as the key steps of an impact assessment These steps are accompanied by a set of decisions, on e.g. the quality of exposure data, availability of the health data and applicability of the ERFs at a given scale level (see left column) and a set of conditions, such as the underlying assumptions, the expertise needed to perform the HIA and the preferred way and scale of presenting the results (right column).

After these decisions have been made and the conditions as described above are met the actual HIA can take place.

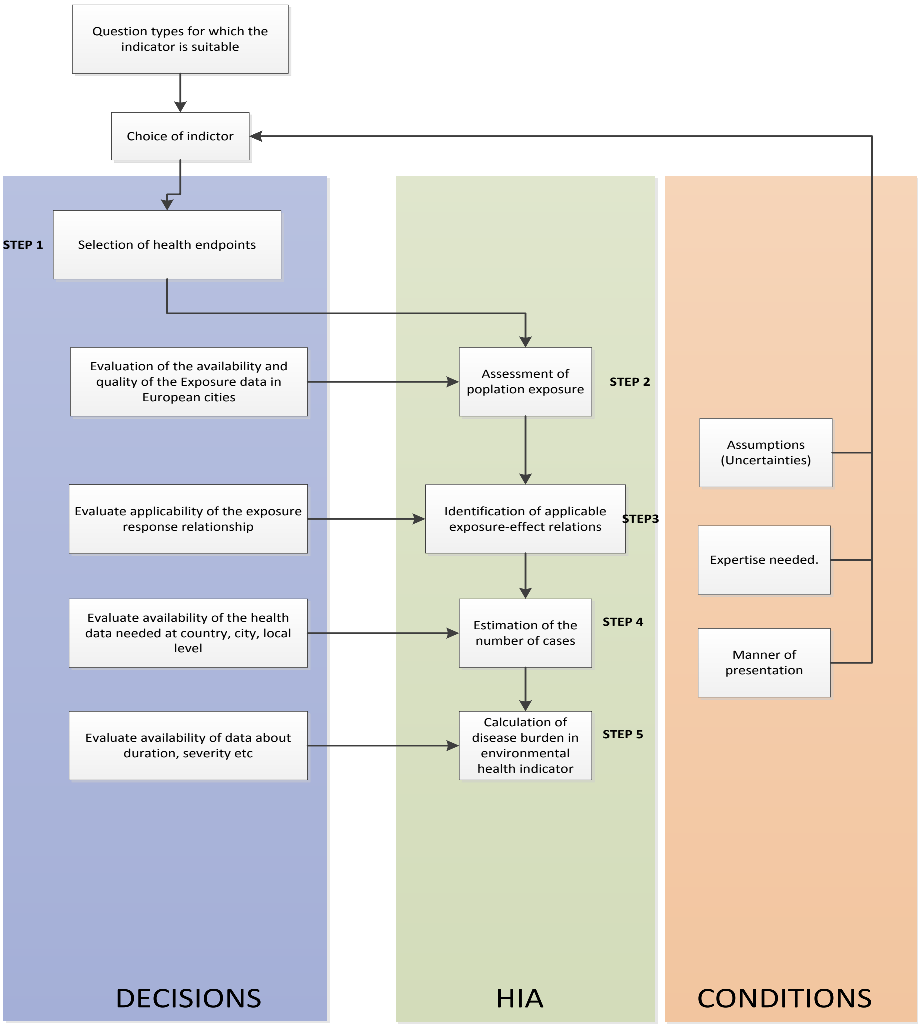

Figure 2.1: Steps in evaluation process at different layers

2.1.1 Policy Questions

Starting point of a HIA are the policy questions to be addressed. These questions strongly determine whether a HIA is a suitable tool to answer the questions and whether a given environmental health indicator is suitable for the task at hand.

These questions of course do not only pertain to environmental noise, but often are part of larger questions about the impacts of infrastructural plans or choices for actions at specific locations. In the context of END we focus on the noise related questions. Roughly these questions can be subdivided in the following main policy questions:

1. Mapping the current status in terms of exposure and their health effect
    a. At different scale levels.
    b. For different social groups.
2. Choice of and prioritization of location of the actions.
3. Choice of mitigating actions with highest impact.
4. Evaluation of noise action plans (NAPS).
    a. Evaluation of the health impact of different actions.
    b. Evaluation of health impact of deviations from limit values.
    c. Efficiency analysis of a set of interventions (monetization).[3]

Within the domain of NAP's a further and gradual distinction can be made between 1) Questions pertaining to the magnitude and extent of effects of environmental noise on human health for a specific location at city level and 2) Questions pertaining to the development and evaluation of more detailed components within a NAP, assisting in the choice and testing of alternative actions at a more detailed scale.

These estimates can be made for current and future situations in relation to e.g. major expansions in road, rail or air traffic, or major changes in urban form. Estimating the health impact for current and future situations would for example require the comparison of different scenarios in terms of exposure and effect as a base for the development of broad scale policy options within NAPs.
Questions from category 2 concern the choice (or prioritization) of locations for mitigating actions, such as insulation schemes, noise barriers for roadways or railway lines.. But it can also concern the comparison in health benefits of different actions such as noise barriers on roadways or railways versus actions at the source (quiet roadway surfaces or rail grinding). These health benefits are usually weighted against the cost in an efficiency analysis.[3]
For some of the questions a qualitative analysis or review of different policy alternatives would be sufficient, while in other cases a quantitative comparison might be needed.

[3] Efficiency Analysis is not included in the methodology described in this guidance document

It is important to note that most of the ERFs for the health outcomes for environmental noise are non-linear. For this reason it is essential, in estimating the magnitude of health benefits from a public health point of view, that results from different action plans are compared based on the magnitude of the resultant change in the health effects, not just on the change in noise levels that result from the action plan. A recent systematic review of transport noise interventions[6] and their impact on health noted that, in decades of environmental noise interventions (or noise management, or noise control), only a very small number of studies estimated the effect of the interventions in terms of health outcomes rather than in noise level changes.

That review also provided an intervention framework showing system components of the path between environmental noise and human health and where different types of noise intervention potentially act along that path To lower the level at the receiver side interventions on each part of the path can be made. At the source side, emission levels can be changed (road surface change or traffic flow change) or time restrictions on use of vehicles can be placed (type A intervention). In the transmission path, barriers can be placed to change the path between source and receiver or the building envelope can be insulated (type B intervention). In addition, the location of dwellings in relation to infrastructure can be changed to make the transmission path from source to receiver longer (type C intervention). These intervention types are summarized in figure 2.2.[6]

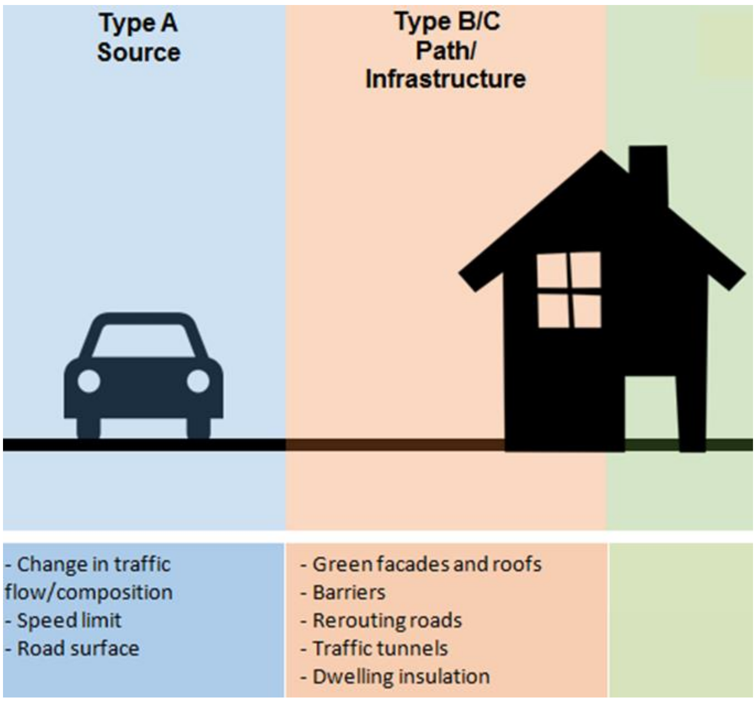

Figure 2.2: Type of Interventions

2.2 Choice of indicators

2.2.1 *Conditions*

The next step preceding a HIA is the choice of suitable indicators. As we saw above the policy questions primarily determine the suitability of the environmental health indicator. When the question for example is aimed at determining hotspots for mitigation actions detailed noise maps would suffice, while the evaluation of the health impact (retrospective or prospective) of noise of mitigating actions demands a HIA by means of an indicator summarizing the impact of noise on different health outcomes. In this choice also three other conditions have to be met: the assumptions underlying the indicator, the expertise available and needed to apply the indicator and the preferred way of presenting the outcomes for the specific aim and at what scale level.

Condition 1: Assumptions (Uncertainties)

When calculating the disease burden, several assumptions and choices have to be made. For example, HIA's usually apply ERFs derived from a study in one population to estimate impacts in another. Such assessments assume that the ERFs are transferable from one group to another and in some cases from one noise source to another. The validity of this assumption implicitly requires that the two populations are similar with regard to factors that influence the magnitude of the exposure response estimate, such as the age and gender distribution of ill-health in the population under study, basic health status, or noise source (See also step 3 in figure 2.1).

Another issue concerns thresholds: there is still no consensus at what noise levels the risk of acquiring a disease starts to increase because these relationships are sigmodal in nature, with no clear-cut threshold value. For some outcomes that show linear relationships, such as reading and others it can be difficult to determine where an effect begins as there is no sharp increase in the effect. While the END noise data assume that serious effects are only visible and relevant above 55dB$L_{den,}$ the Environmental Noise Guidelines[7] (in press) are likely to prescribe much lower guideline values. Also the quality of the data such as uncertainties in e.g. exposure assessment or ERFs relationships, can strongly impact the estimated burden of disease. The extent in which this is the case is indicator specific. In paragraph 2.3.6 the uncertainties are described for each selected indicator in more detail and how they may affect the results of the impact assessment.

Condition 2: Expertise needed

For a HIA within the END framework there is a need to put competent local authorities in a position to derive health effects of the noise action plans and to compare these against alternative solutions. HIA demands a combination of expertise at the level of exposure, epidemiology, public health and in some cases economy. See also recommendations regarding Human resources in http://www.who.int/healthinfo/nationalburdenofdiseasemanual.pdf
Expertise needs are also presented per environmental health indicator in paragraph 2.3.6.

Condition 3: Preferred way and level of presenting the results in view of the aim
Depending on the aim of the HIA it can be applied at different scales (e.g. city level, postal code level). The different indicators produce different results which can be presented in different ways (e.g. in tables, graphs, maps). Since the scale level for which this is done affects the estimates and the interpretation it is important to address them together with the presentation mode. In the section below this will be discussed for each environmental health indicator.

2.3 Environmental health indicators

Over the past decades several environmental health indicators have been constructed to integrate health loss and burden of disease at the population level. Since the late nineties we see a trend towards new environmental health indicators seeking to combine mortality with morbidity, functional and quality of life dimensions. Internationally, this development has given rise[8] to two different movements. One aims to develop a large number of standardized indicators (EU, Denmark), such as mortality rates for specific age groups or the prevalence of specific diseases, while the other builds on the idea that it must be possible to combine the many indicators into one single summary measure of the state of health, such the DALY or costs .[9,10,11,12,13] Within the domain of summary environmental health indicators , a further distinction can be made between health expectancies and health gap indicators. These so-called summary environmental health indicators have increasingly been applied in national and international studies. Although the literature does include many reviewed studies, only a handful of the more recent publications are related to environmental noise[14-25] and several address the pros and cons of different measures [26,27] in particular the disease or health weighted life years, and different approaches to cost benefit analysis.

In the methods to map environment and health a distinction can be made between more qualitative and more quantitative methods.[28] As shown in table 2.1 there is a certain hierarchy in approaches (category a-e), in the sense that the types of indicators move from more simple, qualitative methods (a, b), towards the more complex ones which quantify exposures and effects, or integrate effects (c-e)[4]. As stated before the underlying questions and the phase in the planning process primarily determine which indicator is more suitable and worth the extra effort in terms of time, expertise and data needs.
Broadly, a distinction can be made between the following types of (summary) environmental health indicators (Table 2.1).

[4] The "f" category falls outside this hierarchy

Table 2.1: Overview of type of noise and health indicators with examples

	Type	Examples	Advantages & Disadvantages
a)	Noise Exposure based indicators	• Number of dwellings exposed to certain noise level • Distance to source of sensitive premises (e.g. road)	*A:* data usually available, relatively few uncertainties Allows for monetization *D:* no immediate view on health consequences; no information about effects, potential exposure-misclassification (at level of dwelling)
b)	Environmental quality Indicator of noise level	Compliance with the WHO Guideline values/threshold values in terms of 1) a simple yes/no 2) the difference (Δ dB) to WHO Guideline values/threshold	*A:* data usually available *D:* no immediate view on health consequences; unclear 'direction' of the net health consequences of changes in exposure of different noise sources; imprecise, in particular for the ranking of noise abatement actions measures
c)	Integrated environmental quality indicator	• Health Effect Screening(HES); • Cumulative Health-based Environmental Risk Indicator (CHERIO)	*A:* exposure data usually partly available; relatively few uncertainties D: Focus on multiple exposures; Often non-comparable health risks between factors at same quality level; Sometimes focused on cumulative impact, and not on underlying factors
d)	NafP	• Number of people highly annoyed (HA) • Number of people highly sleep disturbed (HSD) • Number of people with extra risk for cardiovascular effects	*A:* immediately based on health effects; easily understood; allows for monetization *D:* not always valid[5]; not immediately usable for considering changes in several health effects; more uncertainties than a) and b); additional data for health effects required (e.g. baseline risks); more relevant when calculated for combined sources
e)	Integrated health indicators (magnitude of the total health effects on people)	• Disease, health weighted life years (Disability adjusted life years, Quality of Life adjusted life years (DALY's, QALY's) 1. Years lost due to disability (YLD) 2. Years of life lost (YLL) • Health adjusted Life expectancy	*A :* Allows for some judgement about the net effect of changes in dissimilar health effects; allows for monetization *D:* hard to interpret and hard to understand for non-experts; abstract; focus on multiple exposures, since it is a relative indicator; exposure data usually partly available; additional data for health effects required (for example baseline risks); Sometimes focused on cumulative impact, and not on underlying factors;

[5] Expression in terms of effects size is not always the most valid way to present when we are dealing with the effects of long term exposure and combined risk (eg noise and air pollution)

	Type	Examples	Advantages & Disadvantages
		(HALE) • Loss of life expectancy (LLE)	changes in the indicator are not always traceable to the underlying cause and/or health effect; more uncertainties than the other indicators due to more intensive data needs/inputs and value based assumptions
f)	Other indicators mixing exposure and/or health effects with population characteristics (like deprivation, demography, etc.)	• Sustainability index • Liveability index • Socio economic status • Costs of interventions • Multiple environmental deprivation index • Integrated Environmental Index for application in land use Zoning • Züricher Fluglärm Index	A: Accounts for local context D: International application is limited

While not an exhaustive list, the indicators mentioned in Table 2.1 can be considered as an overview of the types of indicators encountered in the literature. Several peer-reviewed papers and documents in the grey literature served as basis for their identification.[26-40] We are aware of the fact that at the local level indicators might be used under different names, comparable to the indicators mentioned, but focusing on different aspects. From the categories b) through e) in table 2.2 five indicators were a-priori selected. Criteria for selection were that the indicator: 1) is well documented and applied,
2) applicable at least at municipal level, 3) allows for an evaluation of the cumulative health impact of environmental noise and 4) is a good candidate to be included in the END guidance tool. From categories a-e in table described in table 2.1 five indicators were selected for further examination.

I Compliance with the WHO Noise Guidelines (b in 2.1)
II Health effect screening (c in 2.1)
III Cumulative Health based Environmental Risk Indicator (c in 2.1)
IV Number of people affected (d in 2.1)
V Disability adjusted Life Years (e in 2.1)

Although the focus is on indicators quantifying health effects rather than noise sources, at this stage we also include examples of indicators based on noise exposures (a and b in table 2.1), with the aim to make the final choice of indicators as transparent as possible. Below the pre-selected indicators are described in more detail.

2.3.1 *Compliance with the WHO Environmental Noise Guidelines*

The Environmental Noise Guidelines for the European Region[7](in press), includes guideline values above which health effects are expected for transport related noise sources separately; that is noise exposure levels above which an increased risk of adverse health effects is expected. These values are based on recent reviews/meta-analyses of findings per noise source and health outcome (published in a special issue of the IJERPH,
http://www.mdpi.com/journal/ijerph/special_issues/WHO_reviews).[41-47]
Deviations from the guideline values could be expressed in:

- a simple yes or no or a difference in exposure levels,
- a difference (Δ dB) to WHO Guideline values/threshold.

2.3.2 *Health effect screening*

The Health effect screening (HES) is a screening method to assess, compare and map a set of environmental exposures with a set of health effects, also below threshold values. The HES-contour maps indicate where health will be more, less or not affected by the environmental exposure under study and can be helpful in the development of new infrastructural plans. The map of dwellings indicates where the health problem areas are expected. Different action plans can be compared with this method. The HES-method relates the environmental impact to an environmental health quality rating and its corresponding HES-score and colour coding. The HES score can vary from “very good” (0) to “insufficient”- in meaning of below standard (6) and “very poor” (8). The corresponding colours are green, yellow and orange to red and purple. For most environmental aspects, including noise, health effects can occur below the legal threshold values, therefore health benefits can also be gained below this level. (https://www.ggdghorkennisnet.nl/thema/ges/publicaties/publicatie/5888). The results of the HES can be presented in maps and tables. Figure 2.3 shows as example the HES contour map of the province of Utrecht in the Netherlands.

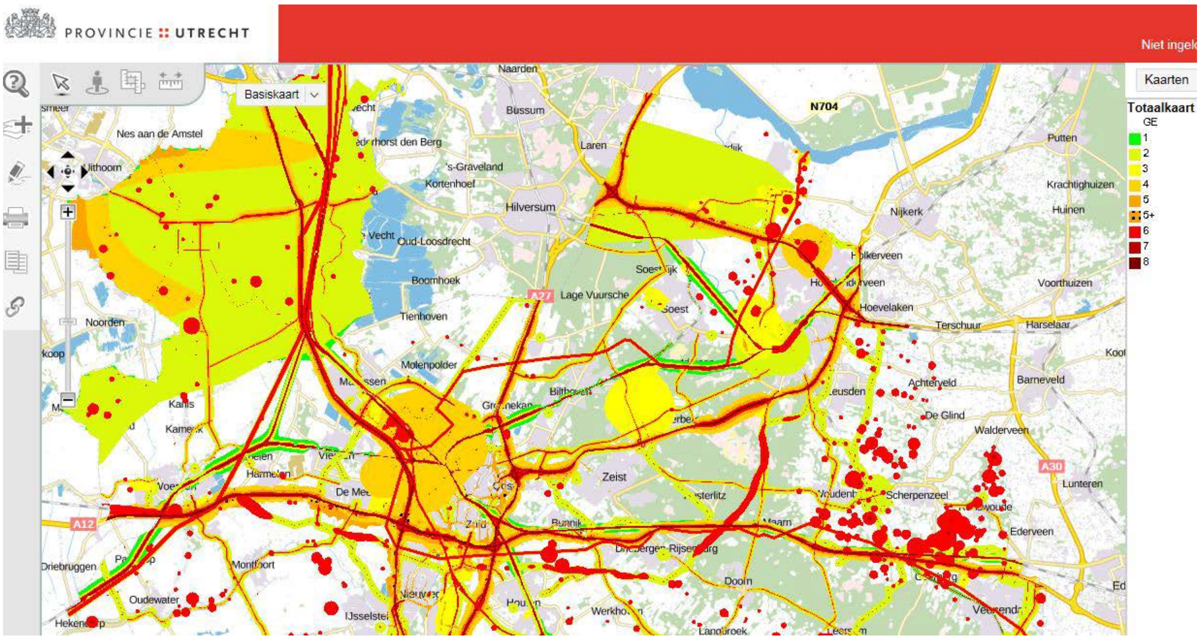

Figure 2.3: HES contour map of the province of Utrecht, Netherlands

2.3.3 *Cumulative Health-based Environmental Risk Indicator (CHERIO)*

The CHERIO aims to identify locations where (future) residents are at an increased risk due to accumulated environmental exposures. It is the burden of disease expressed in a percentage at a specific location attributable to environmental factors compared to the total burden of disease in the same population and is thus country or region specific. It can also be used to compare the environmental health risks between action plans, alternative scenarios, areas and/or groups and to prioritise by comparing the differences in environmental health risk per noise source. The way the CHERIO is calculated is comparable with that of the DALY, which is described in section 2.3.5. However, the way of calculation is simplified in such a way that only the environmental exposures are needed to calculate the CHERIO. Other data, like severity weights and demographic information, are predefined in the CHERIO calculation. If the effects of a policy intervention are assessed, there is also a need for data about the consequence of the intervention on the exposures. The location specific CHERIO can be mapped using a colour coding on a map at address level, as grid or as contours. The CHERIO can also be averaged over an area such as a postal code area or municipality.[28, 29] The mean CHERIO is the burden of disease due to environmental factors as percentage of the total burden of disease in the same population.

The CHERIO[29] is a measure of environmental quality from a health perspective. More specific it can be defined as the percentage of the average time lost each year due to ill-health, disability or early death due to all diseases, for each inhabitant. It includes the health effects of air pollution (extra mortality due to NO2 and PM10) and noise (% highly sleep disturbed, extra cases due to cardiovascular disease (CVD) and DALYs due to reading impairment in children between 7-17). The outcomes of a HIA using the CHERIO approach can be mapped or presented in tables.

The figure below presents the cumulative CHERIO for the city of Utrecht, expressed in postcode (street) areas. For the interpretation we have to bear in mind that the mean value for CHERIO is 5.7 in the Netherlands

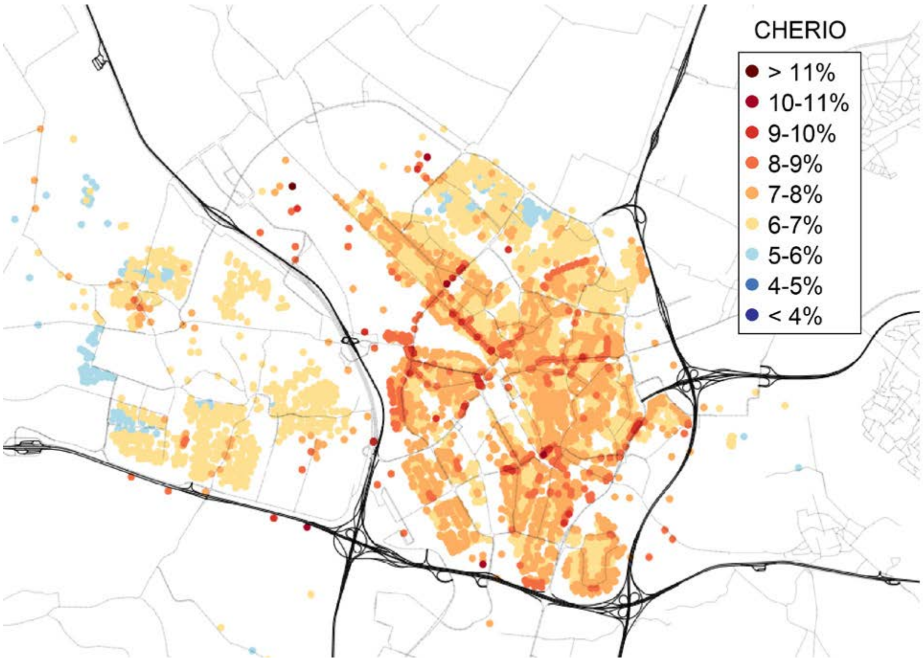

Figure 2.4:Cumulative CHERIO for the city of Utrecht for clusters of addresses (2011)

In the table below the CHERIO for the 10 largest cities in the Netherlands is presented.

Table 2.2: CHERIO of the 10 largest municipalities in the Netherlands and their rank amongst the 40 largest municipalities (2011)

Municipality (ranked according to size)	*CHERIO (% of disease burden and rank)*	
	Cumulated	*Noise only*
1. Amsterdam	7.63 (1)	1.85 (2)
2. Rotterdam	6.90 (3)	0.87 (19)
3. 's-Gravenhage	6.36 (14)	0.73 (29)
4. Utrecht	6.77 (6)	1.10 (8)
5. Tilburg	6.36 (15)	0.88 (17)
6. Eindhoven	6.41 (11)	0.84 (22)
7. Almere	5.45 (34)	0.56 (38)
8. Breda	6.23 (21)	0.80 (25)
9. Groningen	5.30 (37)	0.88 (16)
10. Haarlem	6.29 (19)	1.15 (6)

2.3.4 *IV NafP (Number of people affected by noise)*

By combining the number of people exposed to a certain noise level with available ERFs, demographic data, incidence and prevalence data the NafP can be estimated. This can be calculated for single health outcomes: such as the number of people highly annoyed or sleep disturbed, number of extra cases due to cardiovascular disease or the number of children with comprehensive reading impairment. However, the different health outcomes can also be summarized into one single number. The main issue by doing so is the problem of double counting.[48] By simply adding up the number of cases or number of people we tend to overestimate the effects, as for example, people who are sleep disturbed may also be annoyed by noise. When comparing the effectiveness of different actions (thus using a relative number for different health outcomes) this might not pose a problem (see further paragraph 3.6).

2.3.5 *V DALY (Disability adjusted life years) and related indicators*

The DALY aims to provide insight in health loss due to environmental exposures. The DALY allows for comparisons, prioritizing and considering of incomparable health effects or different environmental factors or different sources within one factor. The DALY is thus a relative number: the absolute number is meaningless.
For a population, the health lost is calculated in relation to environmental exposures. This is expressed in DALYs (Disability Adjusted Life Years) and comprises health lost due to premature death and the number of years lived with a disease weighted for the severity of this disease. There are several ways to calculate the burden of disease. In most cases the population attributive fraction (PAF) is used. This is the proportion of people with a disease which can be attributed to an environmental exposure. In the next step the number of people with a disease due to a given environmental exposure multiplied with the average duration of this disease and the weight for the severity of this disease is calculated. This weight ranges from 0 to 1 (death).
DALYs can be presented in a table or diagram presenting the number of DALYs per year for each environmental factor separately or all factors together in a certain area (country, region, city). Also in DALYs we tend to overestimate the effects (see also 2.3.4) as for example, people who are sleep disturbed may also be annoyed by noise and run increased risk for long term health effects.[48] Originally DALYs were constructed in the framework of the Global Burden of Disease project[49] to integrate health loss at population level by combining years of life lost due to premature death(YLL) with years lived with disability (YLD) that are standardized by means of severity weights.

A well-known early example is the Global Burden of Disease project led by Murray and Lopez.[9,10]
The DALY has been applied in numerous studies covering a whole range of environmental and public health issues[50-55] and including environmental noise.[11-26]

2.3.6 *Further evaluation of the indicators*

In table 2.3 an overview is given for each indicator showing the geographic scale of application, the input data needed and the calculation method. A much more detailed description of the calculation method for the DALY and the NafP is provided as part of the Guidance document in part B.

Table 2.3: Short description of the pre-selected indicators in terms of geographical scale, data needs and calculation method

	Indicator	Scale	Required data	Calculation method
I	Compliance with the WHO Environmental Noise Guidelines	Address	- Exposure data per address (spatial representation) - Guideline values	Either: 1) Verification if being above guideline values in terms of yes/no (hotspots) 2) Calculation of the difference (Δ dB) to WHO Guideline values.
II	Health effect screening (HES)	Neighbour-hood	- Exposure data per address (spatial representation) - Limit values (see guideline HES)	HES relates environmental exposures to health quality rating and its corresponding HES-score and colour coding. This translation of limit values into a HES score is based on annoyance and cardiovascular disease
III	Cumulative Health-based Environmental Risk Indicator (CHERIO)	Address	- Exposure data (spatial representation) - ERF for each outcome - (morbidity and mortality) - ERF for CHERIO (country dependent)	Environmental health risk at a specific place (address, location) is calculated as the percentage of the expected health risks also due to other factors so not just noise The ERF is based on the underlying DALY calculations (see below)
IV	Number of people affected by noise (NafP)	Municipality /neighbourhood under certain conditions	- Exposure data (**<u>no</u>** spatial representation) - ERF for each outcome - (morbidity and mortality) - Demographic data	Either: 1) Calculation of NafP per outcome 2) Stepwise scoring system (e.g. 1st CVD, 2nd–sleep quality, 3rd annoyance). The different effects are not summed up to a single index. The considered effects are presented separately, but in order of importance"[4,5] Hereby defining importance is subjective: one could use high annoyance as a daily stressor, another could choose long term health effects such as IHD.
V	Disability Adjusted Life Years (DALY)	Municipality /neighbourhood under certain conditions	- Exposure data (**<u>no</u>** spatial representation) - ERF for each outcome - (morbidity and mortality) - Burden of disease database- - Demographic data	The following calculation method is most commonly used: Exposure data and relative risks derived from epidemiological data (by means of meta-analyses) are used to derive the population attributable fraction (PAF). Subsequently, this fraction is applied to the burden of disease figures as given in the WHO global burden of disease database or the burden of disease database of a relevant country. In general, information about population exposure (*in casu* environmental noise) , an exposure-response function and (in some cases) background incidence data are needed in order to estimate the environmental burden of disease. Over the years different methods for deriving the environmental disease burden have been used. These methods differ in how they derive the population attributable fraction, and in whether burden of disease figures are derived from WHO or national burden of disease database or estimated using disability weights and duration factors.

2.4 Final selection of indicators for the END Guidance document (Annex III)

2.4.1 *Selection criteria*

Further selection of indicators for the guidance document (B) was primarily based on their potential to describe the health effects of exposure to environmental noise in the general population. Other important requirements were that the indicator should be clear, simple and scientifically sound. According to Briggs et al.[3] this means for example that the indicator is unbiased and representative of the conditions in question, scientifically credible, reliable and valid, is robust, consistent and comparable over time and in space. In relation to clarity and simplicity, the (summary) environmental health indicator should amongst others be readily understandable by interested parties and potential users.

2.4.2 *Procedure*

From different documents[3, 4, 5] and consultation with different experts, criteria have been collected which could guide the selection of suitable (summary) environmental health indicators. Although the criteria are worded diversely in the different documents there is considerable overlap between them. This resulted in a list of eleven criteria, which were further narrowed down into the following eight.
The indicator has to be:

1. Relevant to quantify health effects of noise
2. Relevant for policy use
3. Capable to reflect changes in noise exposure
4. Flexible and adaptable to new ERF's, severity weights and guideline values
5. Scientifically sound
    a. Unbiased (not affected by other parameters than noise)
    b. Reliable (in the sense that it is robust and unaffected by minor changes)
    c. Acceptable (in the sense that it is widely used, not widely criticized)
6. Based on available data of acceptable quality
7. Easy to implement
8. Understandable for the general public

2.4.3 *Stakeholder Consultation (Delphi)*

Stakeholder consultation was performed using the so called Delphi method. The Delphi method is a structured communication technique or method, originally developed as a systematic, interactive forecasting method which relies on a panel of experts. The Delphi method is based on the assumption that group judgments are more valid than individual judgments. The experts usually answer questionnaires in two or more rounds. On average at least 15 people should be participating in a Delphi consultation. The Delphi consultation comprised three rounds in which people first answered 7 open questions, next coded statements derived from these open questions were presented and in the final round a matrix of (summary) environmental health indicators on the 8 criteria was scored on a 5 point Likert scale.

In total twenty people have been invited to participate in the first Delphi Round of whom 12 responded. The participants formed a mix of noise experts, psychologists, epidemiologists, civil engineers and people working in the field of environmental policy. After an inventory of some demographics, professional background, country and expertise in the field of the END 58% considered themselves as at least somewhat experienced in the field. Most participants had a university education, and most of them (80%) were involved in the noise and noise abatement field. The participants represented eight EU countries.

Delphi Round 1
In the first round invited people were asked to complete an open inventory about the use of environmental health indicators in the European Noise Directives. Also they completed some demographic questions.

Delphi Round 2
For round two , 133 statements were derived from the responses given in round 1. The 20 original participants were asked to score all statements on a 5 point Likert scale. Factor analysis (PC and Varimax rotation) on the statements revealed a 9 factor structure together explaining 86% of the variance. The factors could be reduced to three interpretable factors based on the 'Eigenvalues' (explained variance of 68%) and these concerned the following themes: Requirements of the indicators, aims of impact assessment and underlying questions and inclusion of health in policy and END (for the original themes see Appendix I).

Delphi Round 3
Based on further refinements of the requirements based on round 1 and 2, in the third round the external participants and nine members of the team were asked to score a matrix of indicators and requirements. In total 19 people completed this scoring. Table 2.4 shows the final set of requirements and the scoring on these. (All participants received the same basic backgrounds about the context of END, the selected indicators and the way the requirements were derived. The scoring was performed online and anonymous, so people could not influence each other's scores. Room was given for comments, additional requirements, additional indicators and scoring of these.

Table 2.4 Linking the pre-selected indicators to the selection criteria (the scale had anchors 1="not at all", 2= "a little", 3= "moderately", 4= "fairly", 5= "very")

indicator →	I Compliance with WHO guidelines	II HES Health effects screening	III CHERIO	IV Number of people affected	V DALY
Criteria ↓	Mean/SD	Mean /SD	Mean/SD	Me an/SD	Mean/SD
1.Relevant to quantify health effects of noise	3.4/1.1	3.4/0.8	3.9/.09	3.8/1.1	3.9/0.8
2.Relevant for policy use	3.9/1.0	3.7/0.8	3.6/1.0	3.7/0.8	3.5/1.0
3.Capable to reflect changes in health effects due to changes in noise exposure	3.1/1.0	3.3/0.9	3.6/1.0	3.4/1.0	3.4/0.8
4. Flexible, adaptable to new ERF's, severity weights and guideline values	3.8/1.3	3.1/0.7	3.2/0.7	3.9/1.0	3.4/0.8
5a.Unbiased 5b.Reliable 5c.Accepted by scientific community	3.7/0.9	2.8/0.8	3.1/0.7	3.5/0.8	3.4/0.9
6. Minimum (END) exposure data available suitable and of sufficient quality for indicator	3.6/1.2	3.1/0.9	3.1/0.8	3.6/0.9	3.5/0.7
7. Simple to implement	4.6/0.5	3.4/0.9	3.1/0.9	3.9/1.1	2.5/1.1
8.Understandable for the general public	4.4/0.6	3.4/0.8	2.9/1.1	4.1/0.8	2.3/1.1
Total score	**30.6/7.6**	**27.3/6.6**	**26.9/7.2**	**29.7/7.6**	**25.8/7.2**

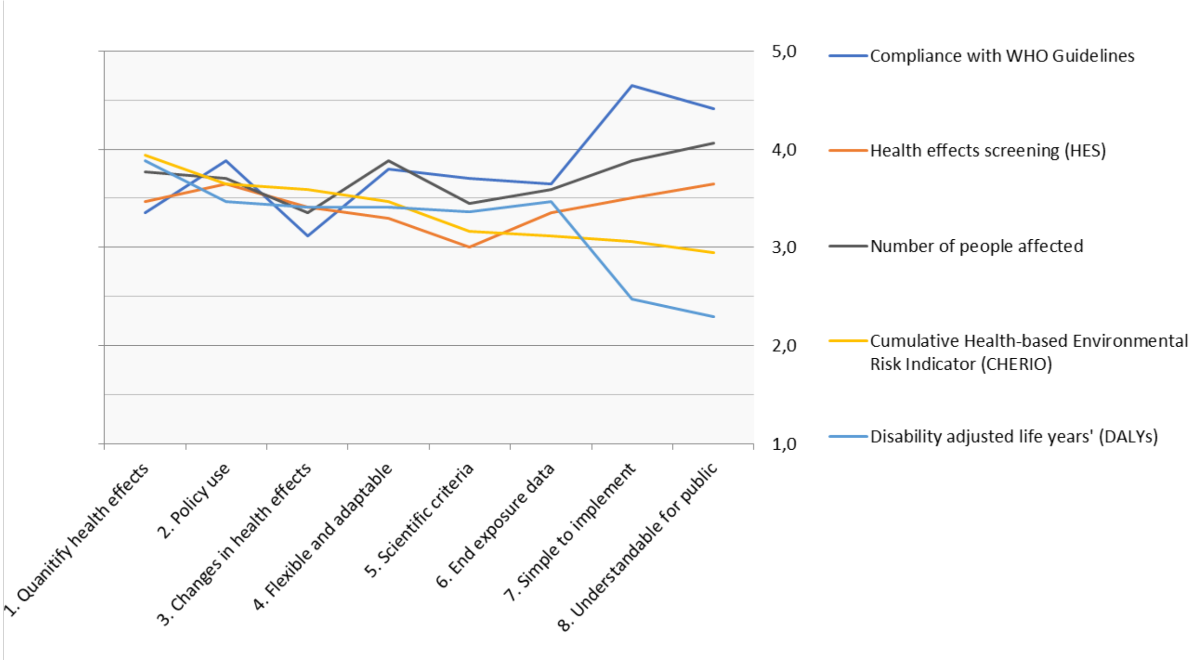

Figure 2.5: Scoring of the five indicators on eight criteria

2.4.4 *Other considerations*

When looking at the policy questions described in paragraph 2.2.1 it can be concluded that indicator I and II are primarily suitable to map the current noise exposures and their health effect and to choose or prioritise locations for policy action. Indicator IV would also allow for the evaluation of the health impact of different actions at low scale level, whereas indicator III and V are primarily suitable for mapping the health status in relation to environmental noise at a higher scale level and over time.

The indicators also differ in the level of uncertainties and expertise needed to perform the calculations and/or interpretation of the results. All indicators share uncertainties related to fixing the boundary of the study area and exposure misclassifications. The DALY and NafP have the advantage that ERFs are directly applied and the uncertainties can be quantified. For the DALY the key uncertainties lie in the quality of morbidity (illness) and mortality (death) figures, which varies per country. With the new calculation methods the uncertainties of weightings and duration estimates of diseases are not applicable any longer (see chapter 3). HES (II) has its own uncertainties related to the fact that the method is based on ERF and limit values and that exposure classes (of for example 5dB) are not very sensitive to change. The uncertainties of CHERIO (III) are primarily related to the simulation of morbidity and mortality for a give population over a longer period of time. As for expertise needs: Indicator I and III require GIS expertise only, II and IV require health expertise for interpretation and advice and CHERIO (III) and DALY (V) more specific environmental health (epidemiological) expertise for interpretation, while for the DALY also at the calculation stage epidemiological expertise is required.

According to Article 1(1c) of the END the public has to be informed about environmental noise and its effects on health and well-being. The information has to be clear, comprehensible and accessible to the public (Article 9 END). Putting all the noise effects in one single number seems not to fulfil the criteria of clearness and comprehensibility. Furthermore, the public is to be consulted about proposals for action plans, given early and effective opportunities to participate in the preparation and review of the action plans (Article 7 and 8 of END). Instead of presenting one single number for the environmental noise source-specific health impact it would fit with the aims of END more closely with regard to the engagement of the public if the public were informed about the different noise attributable health outcomes and could take part or at least be consulted in the decision of what outcome(s) should be protected at what places. This might also include the participation of the local public in the decision of the order of outcomes to be taken up in a stepwise assessment of the impact of different noise scenarios.

To sum up, the choice of summarizing the NafPs versus using the single outcomes versus ranking of the single outcomes, is very much dependent on the context, the aim of the HIA and underlying policy questions.

In most situations the use of single outcomes would be preferred above simply summing up the health outcomes. In line with article 1 (1c) of the END the public people could be engaged in the decision what outcome(s) should be protected at what locations.
The stepwise ranking method as described above is somewhat more transparent than the calculation of a single total health indicator and a reasonable approach when comparing noise scenarios against a baseline scenario or for the assessment of effectivity of actions. For the assessment of the status quo of the health impact of environmental noise in a given area it is less suitable.

2.4.5 *Discussion*

Results show that overall the scoring does not differ that much between the five indicators; the largest contrasts between indicators are found on criteria 7 and 8 pertaining to simplicity of implementation and comprehensibility to the general public. Compliance with the WHO guidelines (I) scores highest on these requirements and the DALY (V) the lowest. Requirement 6 (END exposure data) discriminates least between the five indicators.

Looking at the steps in the HIA (Figure 2.1) it becomes clear that what we originally referred to as different indicators are in fact steps in the impact assessment, e.g. the ERFs and calculation of NafP, can be seen as separate indicators, but are actually also steps in the assessment. Other criteria such as the uncertainties, expertise needs, and data needs also play an important role.
Although CHERIO and HES are good candidates, with less data requirements than the DALY they are not well documented yet at the European level.
The NafP, if summarized, looks suitable for complex as well as simple scenarios.

Based on the criteria we used there is not one measure coming forward as the best candidate. The different indicators seem complementary rather than mutually exclusive, having weak points at one end and strong ones at the other. It is clear that we did not fully solve the riddle yet regarding a compromise between scientific soundness and simplicity. However if we have to make a choice, the NafP scored fairly strong over the whole range of requirement and thus came closest to the compromise between criteria. The less well documented HES indicator and CHERIO, both developed in the Netherlands, had average scores. Compliance with the WHO guideline values is the strongest but being solely based on the noise maps does not add much to Annex II of END (see textbox with assumptions in chapter 1).

Taking the two requirements of the European Commission into account (preferably indicators which summarize the different outcomes and at least include the DALY), the NafP and the DALY were selected as the key indicators to be elaborated on in the Guidance document part B and the practical example in Dusseldorf (part C).

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3 Guidance Document Part B: Calculations

3.1 Introduction

In this chapter we describe step by step the actual process of calculating the burden of disease for the two selected indicators (see Chapter 2):

1. The number of people affected (NafP) (magnitude of people with a health outcome)
2. Disability Adjusted Life Years (DALYs).

First, health outcomes are selected (**step 1,** see also figure 2.1). Next the input values that should be included in the calculations are described; he assessment of population exposure (**step 2**); the identification of exposure response relations (**step 3**); the estimation of the number of cases (**step 4**) and the calculation of the disease burden (**step 5**).

3.2 Step 1: Selection of health indicators

Based on the recently published WHO reviews[1-7] the following outcomes were a-priori considered for inclusion in the HIA. The table indicates for the noise indicators L_{den} en L_{night} whether an ERF is available to relate the noise exposure to the health outcome.

Table 3.1 – List of selected health outcomes

Health outcome	L_{den}	L_{night}
%Highly sleep disturbed - all sources - adults		Percentage of affected people amongst those exposed (per noise band)
% Highly annoyed - all sources - adults	Percentage of affected people amongst those exposed (per noise band)	
Children's impaired reading - aircraft noise	Percentage of affected children amongst those exposed (per noise band)	
CHD (Coronary Heart Disease) Incidence - all sources - adults	Number of cases attributable to noise	
CHD (Coronary Heart Disease) Mortality) - all sources - adults	Number of cases attributable to noise	
Stroke – incidence - all sources - adults	Not included, no ERF available yet	
Stroke – mortality - all sources - adults	Not included, no ERF available yet	

3.2.1 *Sleep disturbance*

There is evidence of sufficient strength for sleep disturbance due to environmental noise to be included in the HIA for the END.[1] In studies investigating the association between noise and sleep disturbance, the percentage of the population highly sleep disturbed (%HSD) is based on a standardized survey question referring to noise (per source). Generalized ERFs resulting from a meta-analysis from these type of studies can be found in table 3.2 , their application in equations #1 and #2). In principle, ERFs for %HSD related to L_{night} are available for the noise sources aircraft, railway, and road traffic. For other noise sources such as, wind turbine and other stationary (industrial) noise sources, the evidence is only emerging and it is not possible to derive reliable ERFs at this point. We acknowledge that self-assessments of sleep disturbance can be problematic, as sleepers are unaware of themselves and their surroundings during large parts of the night. For this reason, it would be advantageous to use ERFs based on physiological indicators of sleep quality/disturbance such as the number of additional awakenings rather than self-reported indicators. However, the number, size, and generalizability of studies on the effects of noise using these measures of sleep is not sufficient. Furthermore an effect such as the number of additional awakenings is related to maximum noise levels/events (LA_{max}), which are very difficult to model with the current noise models and are not part of the END. To increase consistency with WHO's new Environmental Noise Guideline, we decided to exclude the use of ERFs based on physiological measurements of sleep at this point.

For sleep disturbance at present the percentage of highly sleep disturbed (%HSD) is recommended as the preferred indicator.

The source-specific ERFs for sleep disturbance show considerable variation over time and between studies. This indicates that deviations in the %HSD can occur at national/regional/municipal level as compared to %HSD calculated using the generalised ERFs described in this document

In order to assess the actual number of highly sleep disturbed people in a study area in the framework of a NAPs, it is recommended to use local data if available: the results of survey data or ERFs based on local data. In case these data are not available, generalized ERFs can be applied.

In order to compare the effectiveness of (policy) actions or to prioritize actions in the framework of a noise action plan in terms of an increase/reduction in the fraction of highly sleep disturbed annoyed people, generalized ERFs can be applied because the comparison is relative.

3.2.2 *Annoyance*

There is evidence of sufficient strength for environmental noise annoyance to be included in the HIA for the END.2 In studies investigating the association between noise and annoyance, The percentage of highly annoyed (%HA) is based on a standard survey question (ISO/TS 15666:2003, https://www.iso.org/standard/28630.html that refers to the noise source in the question) Generalized ERFs based on meta-analyses of the results of such studies, can be found in table 3.3. In equations #3 and #4, it is demonstrated how these ERFs can be combined with the exposure of the population, to estimate the total number of highly annoyed people. In principle, ERFs for the %HA related to L_{den} are available for the noise sources aircraft, railway, road traffic.

For noise annoyance the percentage of highly annoyed people (%HA) is recommended as the preferred indicator.

The source-specific ERFs for severe annoyance show considerable variation over time and between studies. This indicates that deviations in the %HA can occur at national/regional/municipal level as compared to %HA calculated using the generalised ERFs described in this document.

In order to assess the actual number of highly annoyed people in a study area in the framework of a NAPs, it is recommended to use local data if available: the results of survey data or ERFs based on local data. In case these data are not available, generalized ERFs can be applied.

In order to compare the effectiveness of (policy) actions or to prioritize actions in the framework of a noise action plan in terms of an increase/reduction in the fraction of highly annoyed people, generalized ERFs can be applied because the comparison is relative..

3.2.3 *Cognition*

There is evidence of sufficient strength for impaired comprehensive reading due to environmental noise.[3]
This is based on the results of studies investigating the impact of road or air traffic noise on the reading test score in child populations. In principle, an ERF related to L_{Aeq16h}[6] is available for aircraft noise only and limited to the child population. ERFs and equations can be found in table 3.4, and their application in equations #5 to #8.
The reading test score, per se, is not a health outcome which is easily applied, and this may limit the use of the ERFs available for children's learning. However in the review there are study specific ERFs that could be applied. Results for the RANCH and NORAH study suggest a 10dB increase - for the school day- to be associated with a 1 to 4 month delay in reading age.

At present, the percentage of children with a relatively low score on a reading comprehension test due to aircraft noise could be used as indicator.

Alternatively the percentage of children with a delay in comprehensive reading is recommended as indicator.

3.2.4 *Cardiovascular Effects*

For coronary heart disease (CHD) and stroke (morbidity and mortality) there is evidence of sufficient strength for an association with environmental noise. As will be described in section 3.4.4. However, the

[6] L_{Aeq}, 16h can in some cases be transformed in Lden see also section 3.5.3

ERFs that were derived as part of the WHO review [4,5] (see also table 3.5 and 3.6), are not all valid for use in a HIA. End points such as hypertension and diabetes were excluded: hypertension is not considered as health outcome, but rather as risk factor and as such sufficiently covered by CHD. Diabetes was not included because the available evidence[4,5] is based on a limited number of studies.[7]

In equations #9 to #10, we demonstrate how these selected ERFs can be applied to estimate the percentage (or number) of people with one of the cardiovascular endpoints due to noise exposure.

3.2.5 *Other effects*

Birth Outcomes

In the WHO review, studies on the impact of environmental noise on birth outcomes such as pre-term delivery, low birth weight and congenital anomalies were evaluated. The evidence from these studies was mainly rated as low; also it was not possible to quantify the association between environmental noise exposure and one or more of these outcomes. There is insufficient evidence[6] to justify the use of adverse birth outcomes as health endpoints in a HIA of exposure to environmental noise.

Hearing Loss and Tinnitus

In the WHO-review no evidence is presented for the association between noise from road, rail or aircraft noise and hearing impairment and tinnitus. There is insufficient evidence available[7] to justify the use of adverse permanent hearing outcomes as health end points.

3.3 Step 2: Input data sets

In order to calculate the NafP of people/cases (step 4) affected and/or the number of DALYs (stap5) , data are needed. These include the incidence of effects (e.g. the number of highly annoyed and/or, highly sleep disturbed people, the number of people with CHD per year attributable to noise, the number of people that died due to CHD due to noise exposure, years of life lost due to disability (YLD), and the years of life lost due to premature mortality(YLL).

In order to calculate the different indicators, the following input data is needed for the study area:

1. The fraction and number of residents per noise category (step 2)
2. Demographic data of the study area (step 2)
3. Exposure response relations (step 3)
4. Disease and mortality data valid for the study area (step 4).

Before we demonstrate how the calculations in the different steps can be performed, we explain how these inputs can be obtained.

3.3.1 *The fraction of residents per noise category of the study area*

In combination with fixing the boundary of the study area carefully the noise exposure distribution of the population living in the study area is

[5] Since then a range of new studies has been published,

[6] LAeq, 16h can in some cases be transformed in Lden see also section 3.5.3

one of the essential pre-requisites, necessary to quantify the NafP by environmental noise exposure in a given area. Given that the study area and study period have been determined, population exposure data can be obtained in several ways.
When the focus is on a limited area and population, noise exposure could be assessed by direct measurements. But for larger populations and longer periods (which is usually the case in a health impact assessment), noise exposure is usually assessed by means of calculations using models, that focus on the noise levels at the façades of the dwellings averaged over a year. Data on noise emission per vehicle, traffic flows, buildings, and terrain are the main inputs of these models. The result is a noise map, expressing noise levels by means of L_{den} and L_{night}. In Figure 3.1 and figure 3.2 an example of the region Düsseldorf for aircraft noise (day and night) is presented.

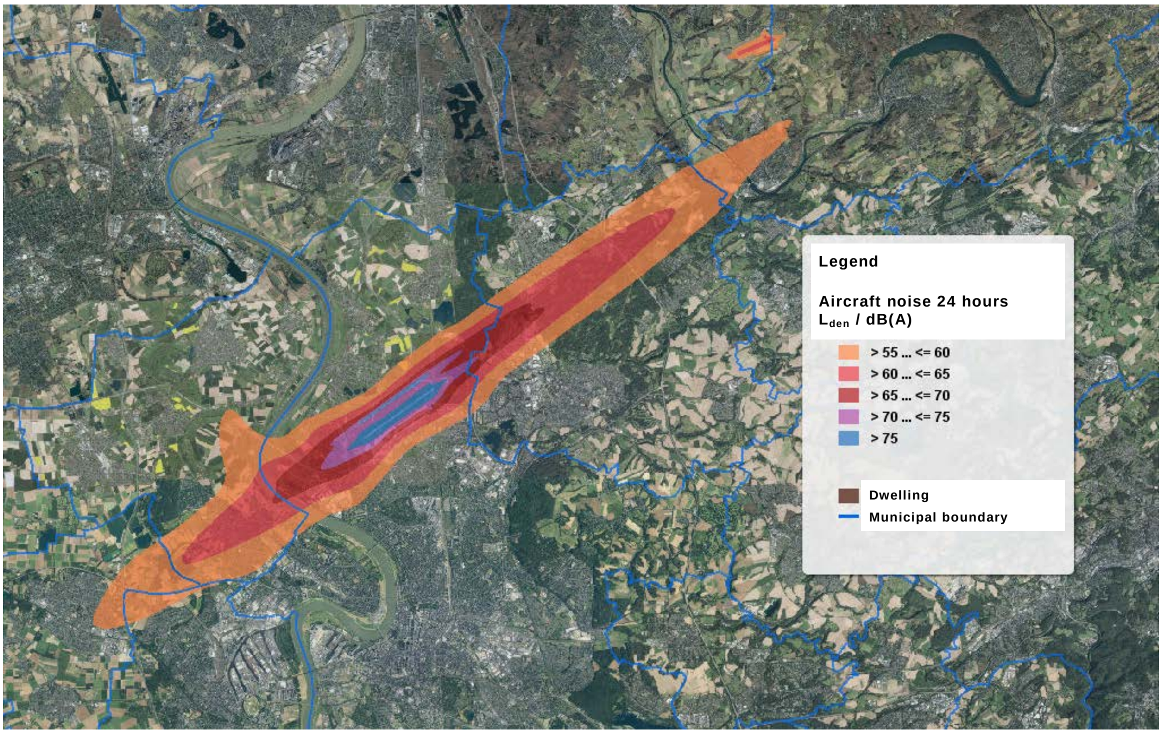

Figure 3.1 and 3.2: Example of a noise map for the Dusseldorf region (5 dB classes) Day and Night

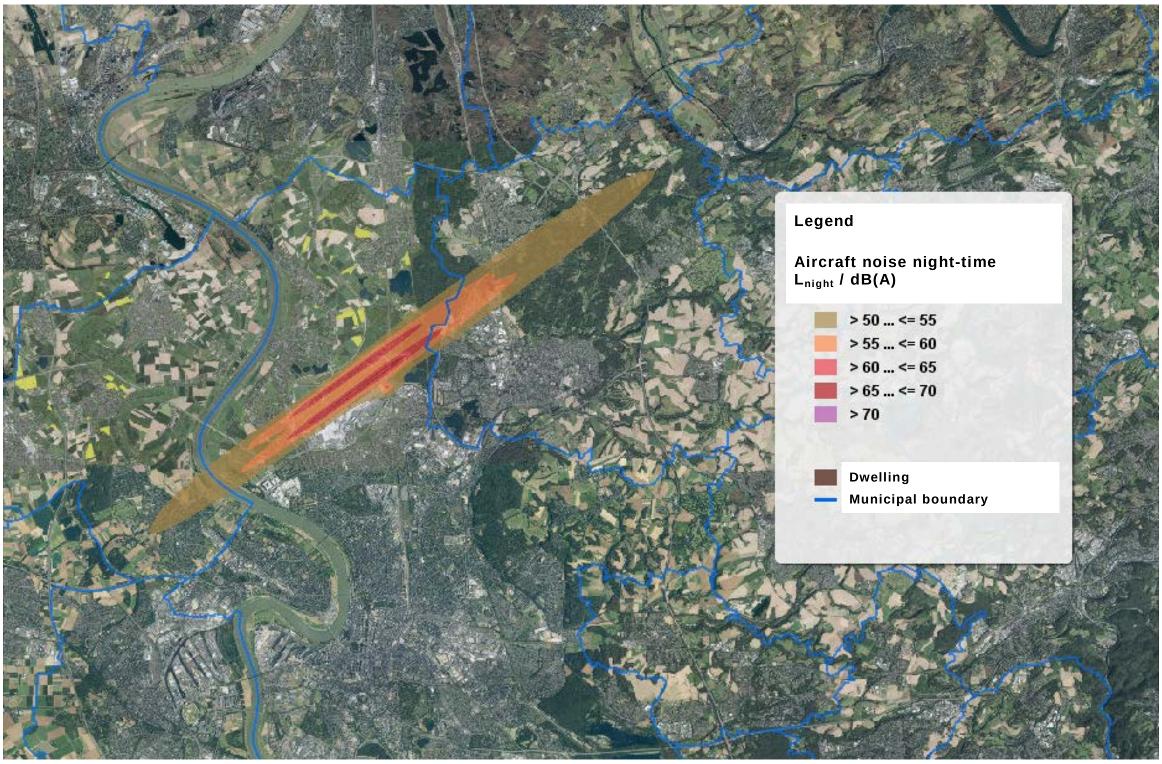

Figure 3.1 and 3.2: Example of a noise map for the Dusseldorf region (5 dB classes) Day and Night

In order to derive the population exposure distribution, the noise map is linked with the locations of residential buildings. This is done within a Geographic Information System (GIS). Noise maps can be obtained from environmental agencies. Data on the locations of residential buildings can be obtained from a Land register and mapping agency or municipality. If this is the method used, it is important to understand the underlying methodology and any uncertainties or limitations involved.

An alternative are the strategic noise maps created in the framework of the European Noise Directive (END).[8] The Directive requires Member States to prepare and publish, every 5 years, noise maps for:

- Agglomerations with more than 100,000 inhabitants
- Major roads (more than 3 million vehicles per year)
- Major railways (more than 30000 trains per year)
- Major airports (more than 50000 movements per year, including small aircrafts and helicopters)

These different maps, together with the exposure distribution can be downloaded from the European Environmental Agency's (EEA) ReportNet system: http://cdr.eionet.europa.eu/. Using the END noise maps has several restrictions. As part of the strategic noise maps, Member States are only required to report to the EU the number of residents per 5 dB (L_{den}) categories, starting from 55 dB (L_{den}) and onwards. For noise exposure during the night, the Member States are required to report the number of residents per 5 dB (L_{night}) categories, starting from 50 dB (L_{night}) and onwards.

However, it is very well possible that also information is available of the number dwellings and/or residents exposed *below* levels of 55 dB (L_{den}) or 50 dB (L_{night}).

It is recommended to obtain exposure information below 55dB (L_{den}) and 50 db (L_{night}) respectively. Preferably from 35-40 dB L_{den} and up where available for the HIA. In case this information is not available, one should realise that the available noise database is incomplete, as is the estimated health impact related to noise exposure.

When only noise exposure distribution is available for the number of residents per 5 dB categories, the question arises what L_{den} -level per 5 dB category should be used for the calculation? The easiest solution is to use the arithmetic mean: so taking the noise category in the range from 50 to 55 dB L_{den}, the arithmetic mean is (50+54.9)/2 = 52.5 dB. Applying the arithmetic mean assumes that for example all the 17,890 residents (in the Dusseldorf case see also Chapter 4) exposed to rail traffic noise levels that fall within this 5 dB category, are equally distributed over the noise levels within this category. A limitation is that we do not know whether this assumption is realistic and how this affects our estimate of the disease burden. Information on the number of residents per 1 dB category may overcome this problem. In the case of Dusseldorf, this information is available, but it is accepted that this level of data may not always be available, hence setting out the method described above.

In quantifying the NAfPs and DALYs the exposure of the population is the starting point. For the interpretation of the findings it would be helpful to study the (cumulated) maps of the selected area in addition to the tables also for the lower exposure levels. An extra advantage of producing a map of the exposure situation is that it illustrates where the hotspots in the study area are located. At the same time this can give an indication of future health effects.

3.3.2 *Demographic data of the study area*

For the different calculations, preferably estimates of mid-year resident populations at risk by age and sex are required. Usually five-year age groups are used. These estimates should be based on the latest/most relevant available population census with annual estimates of mid-year population based on statistics (or estimates) on births, deaths and migration, by age and sex. As an alternative the yearly figure at January 1st can be used.

Population data can be obtained from several sources. The first option is to obtain the data from the local statistics department or municipal health agency if present. Usually these agencies gather data by means of a population census and therefore include estimates of the age-sex composition for the study area.

In case population estimates are not available specifically for the study area, an alternative option is to use national data. If one assumes that the demographic distribution of the study area is similar to the national demographic situation, these data can be projected on the study area.

National demographic data can usually be obtained from the national statistics agencies.

In case the national statistics agency does not produce population estimates, the statistical office of the European Union (EUROSTAT) is a reliable alternative, that can provide demographic data at both country and regional level (http://ec.europa.eu/eurostat/).

The estimations for the number of highly annoyed, the number of highly sleep disturbed, CHD, and reading impairment are made for subgroups of the total population: adults (18 years and older) and children 7-17 years old. CAVEAT: This does not imply that comparable effects do not happen in children, but suitable ERFs for this group are not available yet. When estimating the total burden of disease due to noise this has to be accounted for. For Annoyance and sleep one could consider using the adult ERFs. This would be less appropriate for CHD nor for applying the reading delay ERF to adults.

3.3.3 *Disease and mortality data valid for the study area*

Preferably incidence data for cardiovascular disease at city- or regional level are used. The incidence describes the number of new cases that occur over a specific period of time. For the calculations a period of one year is necessary.

Alternatively, one can use data from national institutes (e.g. a National Statistical Office).

At the international level, the data from the European Heart Network (EHN) are also very useful. The most recent data (2017) can be found at: http://www.ehnheart.org/cvd-statistics/cvd-statistics-2017.html. In the database of EHN (crude) country-specific, data on the incidence of cardiovascular diseases for several years (1990 – 2015) can be found. Together with the demographic data of the study area (see also under burden of disease estimates below), these data can be used to assess the baseline incidence for coronary heart disease and stroke.
Alternatively, data can be found in the European Hospital Morbidity database of the WHO:
https://gateway.euro.who.int/en/datasets/european-health-for-all-database/#morbidity-disability-and-hospital-discharges

Cause specific mortality
The “gold standard” data source for estimating cause-specific mortality is a vital registration, which records at least 70% (and ideally more than 95%) of all deaths occurring in the residential population.
However, such a registration is often not available for a specific study area. Therefore, the national registration can best be used. In most countries national and cause specific mortality data of good quality can be obtained from the National Statistics Offices.
In addition, international organizations gather mortality data for separate countries. A good and reliable source is the Mortality database from the World Health Organization (WHO). These data are freely available and can be downloaded from the website of the WHO:
http://apps.who.int/healthinfo/statistics/mortality/whodpms/. The WHO Mortality database contains country-specific, age- and gender specific

mortality data starting from 1979 up till now. Together with demographic data (see above) these can be used to calculate the baseline incidence.

Burden of disease estimates
Since the 1990s the World Health Organization and the Institute for Health Metrics and Evaluation (IHME) have produced numerous global burden of disease (GBD) estimates, using Disability-adjusted Life Years (DALYs). The results of these studies over the years can be found at the website of WHO:
http://www.who.int/healthinfo/global_burden_disease/en/. For each country, age- and sex specific estimates of the number of Years of Life lived in Disability (YLD) and the number of Years of Life Lost due to premature mortality (YLL) for different diseases are available for download.

Burden of disease estimates are also national and sometimes even at local level available. As part of a recent review by O'Donovan et al.[9] 198 studies were identified that produced DALY estimates for (i) a certain population, (ii) a geographic area within the WHO European Region, (iii) that build on or modified the WHO and IHME estimates, or (iv) concerns independent research that does not include WHO or IHME estimates.

3.4 Step 3: Exposure response relations

3.4.1 High sleep disturbance

Definition: A disorder of sleep patterns which may be high enough to interfere with a person's normal physical, mental and emotional functioning, comparable to insomnia (ICD-10: F51).

The actual percentage or number of highly sleep disturbed people in the study area can be assessed directly by means of a survey, using a standard question comparable to ISO/TS 15666:2003, among a representative group of people living in the study area. The actual number of highly sleep disturbed people can also be assessed indirectly, by means of calculations where source-specific ERFs are combined with population exposure distributions. Preferably, these ERFs are based on data from local studies of sufficient quality. In case ERFs based on local data are not available, one could assess the percentage or number of highly sleep disturbed people by applying generalized ERFs. It is also possible that instead of presenting the actual situation, it is needed to prioritise/choose between mitigating measures. In that case both ERFs based on local data and generalized ERFs can be applied, depending on what is available.

The most recent generalised source-specific exposure response equations for highly sleep disturbed are given in table 3.2 and figure 3.3. For industry a source-specific exposure response equation is still lacking.

Table 3.2 Generalized exposure-response functions for high sleep disturbance (%HSD) in relation to Lnight for road traffic, railway and aircraft noise1

Noise source	**Source-specific exposure-response equation for high sleep disturbance**
Aircraft	100*(exp(-4.7077+(L_{night}*0.0661))/(1+exp(-4.7077+(L_{night}*0.0661))))
Road traffic	100*(exp(-6.8968+(L_{night}*0.0754))/(1+exp(-6.8968+(L_{night}*0.0754))))
Rail traffic	100*(exp(-8.2977+(L_{night}*0.1118))/(1+exp(-8.2977+(L_{night}*0.1118))))
Industry	NA

[1] Derived from Basner and McGuire[1] , Supplement tables S9-S11 ; NA: When writing this manual, no generalized exposure-response were available

The relationship between night time exposure due to air, road and rail traffic was also presented as polynomial function (equation). However, for these equations no 95% tolerance intervals are available. The equations presented in the table were based on the results of mixed models. The 95%CI of these equations can be determined by means of the parameters presented in tables S9-S11 in the supplement of Basner & McGuire. In this supplement the 95% confidence intervals are only presented graphically. In the supplement, the 95% confidence estimates for 40, 45, 50, 55, 60 and 65 dB (L_{night}) are presented (table S15). Applying this information could give an indication of the range of variation..

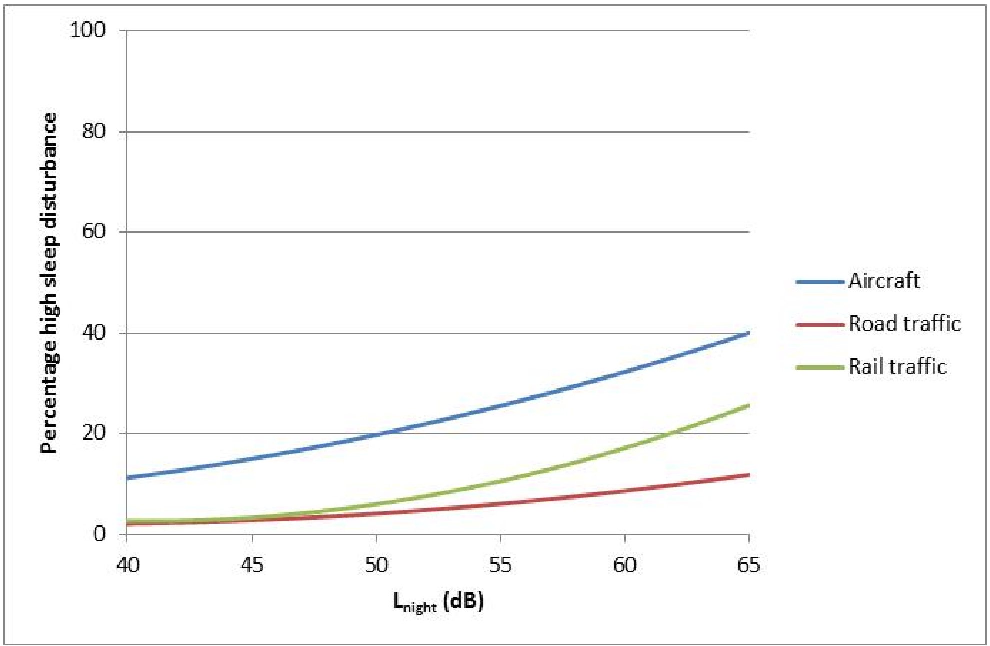

Figure 3.3 Percentage of highly sleep disturbed from aircraft, road traffic and railway noise as function of Lnight 1

3.4.2 High annoyance

Definition: A multi-faceted stress-reaction involving an environmental threat and individual physiological, emotional, cognitive and behavioural responses"[2] or a psychological stress response to uncontrollable noise exposure related to (sustained) physiological activation.[10]

The actual number of highly annoyed people in the study area can be assessed directly by means of a standard question in a survey (ISO/TS 15666:2003), among a representative group of people living in the study area. The actual number of highly annoyed people can also be assessed indirectly, by means of calculations where source-specific ERFs are combined with population exposure distributions. Preferably, these ERFs are based on data from local studies of sufficient scientific quality.

When these are not available, one could assess the number of highly annoyed people by applying general exposure-response functions. It is also possible that instead of presenting the actual situation, it is needed to prioritise/chose between mitigating measures. In that case both ERFs based on local data and generalized ERFs can be applied, depending on what is available.

The most recent generalised source-specific exposure response equations for high annoyance are given in table 3.3 and figure 3.4.

Table 3.3 Generalized exposure-response functions for high annoyance (%HA) in relation to Lden for road traffic, railway, aircraft and industry noise 2,11

Noise source	**Source-specific exposure-response equation for high annoyance**
Aircraft	$(-50.9693 + 1.0168*\boldsymbol{L_{den}} + 0.0072*\boldsymbol{L_{den}}^2)/100$
Road traffic	$(78.927 - 3.1162*\boldsymbol{L_{den}} + 0.0342*\boldsymbol{L_{den}}^2)/100$
Rail traffic	$(38.1596 - 2.05538*\boldsymbol{L_{den}} + 0.0285*\boldsymbol{L_{den}}^2)/100$
Industry	1-Normal£((72-(-126.52 + $\boldsymbol{L_{den}}$) * (2.49)))/sqrt(2054.43))

£Normal refers to a normal distribution: can be implemented in some statistical programmes
For the equations no 95% confidence intervals nor 95% tolerance intervals are available. This means that the resulting estimate (the number highly annoyed people) should considered as an average estimate. No indication of the range can be given.

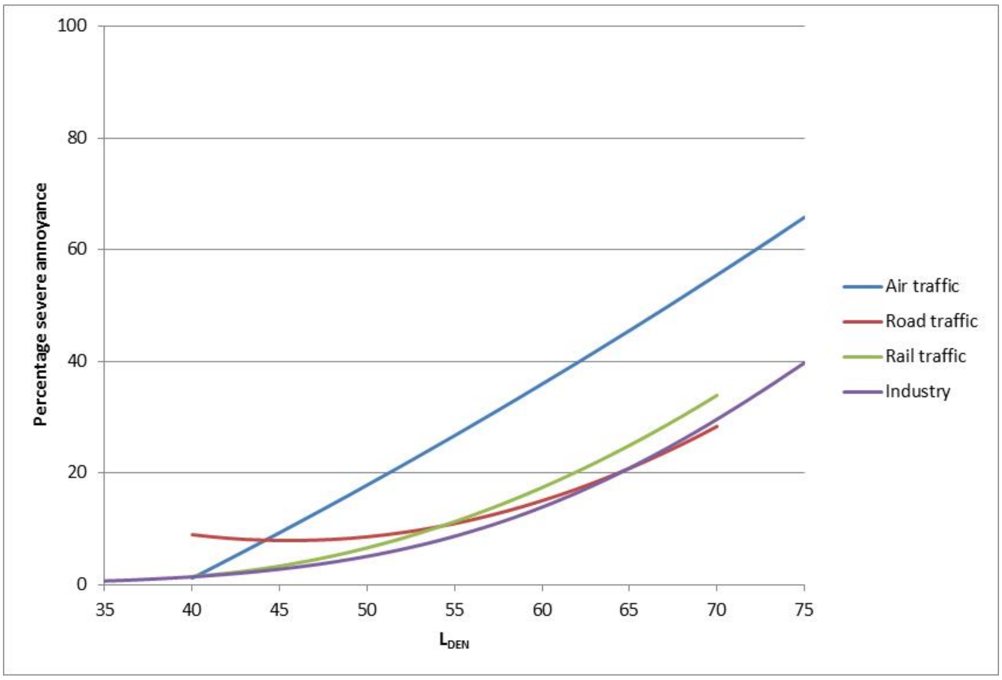

Figure 3.4 Percentage of high annoyance from aircraft, industry, road traffic and railway noise as function of Lden 2,11

3.4.3 *Cognitive effects: Impaired reading comprehension (IRC)*

Definition: *IRC affects the learner's ability to understand the meaning of words and passages. Students with a learning disability in reading comprehension may also struggle with basic reading skills such as decoding words, but comprehension is the greater weakness.*

The actual number of children with impaired reading comprehension due to noise in the study area can be best calculated by means of data derived from local studies. In case these are not available, one could make use of generalised ERFs. As stated above, ERFs are available from two studies, RANCH and NORAH, of which RANCH is the largest study to date.[3] RANCH[14,15] was a multicenter study, that investigated the impact of exposure to road and aircraft noise on children's cognitive functioning in a cross-sectional design. Reading comprehension was one of the cognitive outcomes under investigation. The RANCH-team found that an increase in aircraft noise exposure was statistically significantly associated with a delay in reading ability: a 5 dB increase in aircraft noise exposure was reported to lead to a delay in reaching the required reading ability of 1 to 2 months.[14] An outcome like this allows for comparing the effect of noise to other factors such as gender or the educational level of the parents of the children. Also it can be used to map the total delay in reading months in a given study area.

However, a quantitative HIA is about the NafP in a study area. Therefore, the RANCH data on reading comprehension were re-analyzed[14] and reading impairment was defined as the lowest 10 percentile of the reading scores of the children exposed to noise levels under 50 dB (Lden). More background information on this re-analysis can be found in the following papers. [13,15]
As a next step, the relation between aircraft noise exposure and the probability on reading impairment was assessed for exposure levels above 50 dB. This resulted in an Odds Ratio (OR) of 1.38 (95%CI: 1.09 – 1.75) per 10 dB in aircraft noise level. The prevalence of a reading impairment in case of the absence of noise (baseline) is estimated to be 10% (the lowest 10 percentile).
It should be noticed that the RANCH study, as many other epidemiological studies investigating the impacts of noise on health, used the noise indicator $L_{Aeq,16h}$ (average noise level in day and evening). Since $L_{Aeq,16h}$ is not reported in the framework of the END it was converted into L_{den}.

The ERFs are given in Figure 3.5 and Table 3.4 .

If one decides to include reading comprehension we recommend assessing the additional cases of children with a low score on a reading test for children in their school age (7 to 17 year old) and only in relation to aircraft noise exposure.

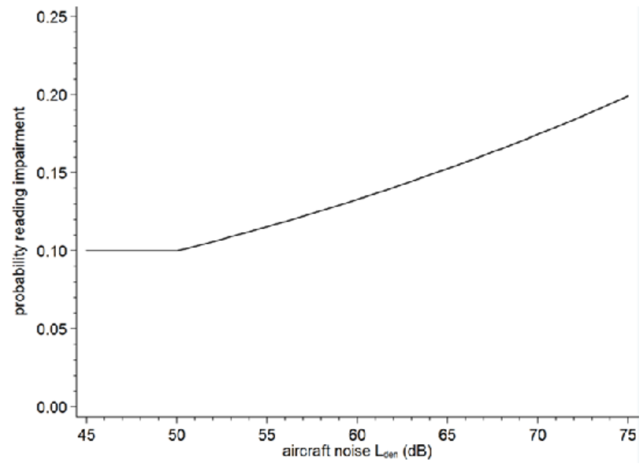

Figure 3.5 Probability of reading impairment among children 7-17 years old as function of Lden (aircraft noise) 3, 14, 15

Table 3.4 Exposure-response function for reading impairment in relation to Lden for aircraft noise

$\int_{\text{reading}}(L_{den})$
1/(1+exp(-(ln(0.1/(1-0.1))+(ln(1.38)/10*(L_{den} -50))))) if $L_{den} \geq 50$ dB L_{den}) 0.1 if $L_{den} < 50$ dB (L_{den})

With: 1.38 is the OddsRatio per 10 dB. The corresponding 95% Confidence Interval is 1.09- 1.75; 0.1 is the baseline prevalence of children with reading impairment; 50 dB L_{DEN} is the value where we assume that the risk for an effect of aircraft noise on reading comprehension starts to increase.

3.4.4 *Cardiovascular endpoints*

3.4.4.1 Coronary Heart Disease

Definition: Coronary heart disease (ICD-10: I20-I25) refers to a narrowing of the coronary arteries, the blood vessels that supply oxygen and blood to the heart.

The relationship between environmental noise exposure and CHD is expressed by means of a Relative Risk (RR)[8] per unit change in noise exposure level. Hereby a linear relationship between noise exposure and the incidence of coronary heart disease is assumed. The most recent RRs per 10 dB on noise and coronary heart disease were derived as part of the WHO evidence review.[4,5] These RRs are presented in table 3.5.

[8] A relative risk or risk ratio (RR) is the ratio of the probability of an event occurring (for example, developing a disease) in an exposed group to the probability of the event occurring in a non-exposed group.

$$RR = \frac{p_{\text{event when exposed}}}{p_{\text{event when not exposed}}}$$

Table 3.5 Estimated Relative Risks per 10 dB for the association between environmental noise and coronary heart disease4,5

End point	Noise source	RR (95%CI) per 10 dB L_{den} (number of studies, design)
Incidence CHD	Air	1.09 (1.04 – 1.15) (2, ECO)
	Road	1.12 (0.85 – 1.48) (1, ECO) 1.08 (1.01 – 1.15) (7, CC CO)
	Rail	-
Mortality CHD	Air	1.04 (0.97 – 1.12) (2, ECO) 1,04 (0,99 – 1,12) (1, CO)
	Road	1,05 (0,97 – 1,13) (3, CC CO)
	Rail	-

Abbreviations: ECO = ecological study, CC = Case-control study, CO = Cohort study; RR = Relative Risk; CHD = coronary heart disease

Based on the results of two ecological studies a positive and significant association was found between aircraft noise and the incidence and mortality due to coronary heart disease. Respectively RRs of 1.09 (95%CI 1.04 – 1.15) per 10 dB (L_{den}) and 1.04 (95%CI 0.97 – 1.12) per 10 dB (L_{den}) were estimated. Based on the results of one cohort study, a RR of 1.04 (95%CI 0.99 – 1.12) per 10 dB (L_{den}) was estimated for mortality.
Also an increase in road traffic noise was associated with significant increases in the incidence of coronary heart disease. This relationship was based on the results of three cohort studies and four case-control studies, and an RR of 1.08 (95%CI: 1.01 – 1.15) per 10 dB (L_{den}) was estimated. No significant association was found for mortality due to CHD 1.05(95%CI 0,97 – 1,13). No associations were reported between rail traffic noise and incidence or mortality due to CHD.[9]
Based on small differences in effect size (see table 3.5) and the fact that the underlying biological mechanism for CVD effects due to noise are the same it can be argued that for HIA-purposes it is best to apply the ERFs based on the studies with the highest quality.

For the incidence of and mortality due to coronary heart disease the ERFs for road traffic are recommended to be used for all sources. For the incidence of coronary heart disease we recommend to use a RR of 1.08 (95%CI: 1.01 – 1.15) per 10 dB and for mortality due to coronary heart disease, we recommend to use a RR of 1.05 (95% CI: 0.97 – 1.13) per 10 dB.

In the near future an update of the ERFs is expected for incidence and mortality due to coronary heart disease supplemented with the results of new studies.[32-40]

[9] We realize that since publication of the WHO review [4,5] several new, high quality studies have been published 32-40 After adding the results of these new studies, the results did not substantially differ from those described in the WHO review. However, because, the ERFs we recommend in this tool, should be based on the WHO reviews, we recommend to use these relationships.

When calculating the RRs at exposure level L_{den} we need to define a threshold above which we speak of exposed and unexposed. In the systematic review[4,5] the estimation of relative risks (RR) was confined to a 10 dB increase in noise level, because different studies used different thresholds for determining the non-exposed group, varying from 60 dB, 55dB to 45dB. In setting these levels, researchers implicitly assumed that no effects of noise would occur below these levels. The choice of a certain reference category may be merely data driven. Ideally a sensitivity analysis should be performed by repeating the calculations for different threshold values in the range between 50 to 55 dB.

We recommend a threshold value of 53 dB (L_{den}). (see chapter 4)

3.4.4.2 Stroke

Definition: A stroke (also known as cerebrovascular disease) (ICD-10: I60-I69) is a medical condition in which poor blood flow to the brain results in cell death.

The most recent RRs per 10 dB on noise and stroke were derived as part of the WHO evidence review.[4,5] Compared with the number of studies on the impact of noise on coronary heart disease, relatively few studies were available that investigated the impact on stroke. The RRs are presented in table 3.6.

Table 3.6 Estimated Relative Risks per 10 dB for the association between environmental noise and stroke 4,5

End point	**Noise source**	**RR (95%CI) per 10 dB (number of studies, design)**
Incidence stroke	Air	1.05 (0.96 – 1.15) (2, ECO)
	Road	1.14 (1.03 – 1.25) (1, CO)
	Rail	-
Mortality stroke	Air	1.07 (0.98 – 1.17) (2, ECO) 0.99 (0.94 – 1.04) (1, CO)
	Road	0.87 (0.71 – 1.06) (3, CO)
	Rail	-

Abbreviations: ECO = ecological study, CC = Case-control study, CO = Cohort study; RR = Relative Risk; CHD = coronary heart disease;

Table 3.6 demonstrates that according to the results of two ecological studies, an increase in aircraft noise was associated with a statistical non-significant increase in the incidence of stroke and mortality due to stroke. This result was only partly confirmed for mortality. Based on the results of only two ecological studies, a positive association was found between aircraft noise and mortality due to stroke. This association was however, not statistically significant. The results of a cohort study showed no effect of aircraft noise in relation to mortality due to stroke. Results for the impact of road traffic noise were not consistent. Only for the association between road traffic noise and the incidence of stroke a statistically significant RR of 1.14 per 10 dB was found, based on one cohort study. No association between road traffic noise and mortality due to stroke was found. Since the work for this evidence review was carried out, a substantial number of new high quality studies has been published that investigated the associations between transportation noise exposure and stroke [32-40]. Preliminary analysis on this new evidence seems to result in figures which deviate considerably from the findings presented in table 3.6, in the sense that the RR for road traffic is lower than reported in the WHO review. For aircraft noise a RR above 1 is expected based on the latest cohort and case studies, which is higher than that reported in the WHO review. In the WHO review [4,5] only one positive association was derived based on the results of a high quality cohort study, namely the association between road traffic noise and the incidence of stroke.

The association between road traffic noise and the incidence of stroke could be used to estimate the number of people with stroke per year due to noise (using the PAF). In case one decides to do this, it is recommended to follow the same calculation steps described for coronary heart disease that will be described in section 3.5.4. However there is some concern about the transferability and generalizability of the ERF.[41]

In the near future an update of the ERFs is expected for incidence and mortality due to stroke supplemented with the results of new studies. [32-40]

3.5 Step 4 and 5: Calculations of number of people affected per health endpoint

3.5.1 *Number of people with high sleep disturbance*

The number of adults (aged 18 years and older)[10] with high sleep disturbance from a specific source per dB L_{night} can be calculated with the following equation:

(eq. 1)

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

Where:

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

The *total* number of adults with high sleep disturbance from a specific noise source can be calculated by summing the number of highly sleep disturbed persons per noise category.

[10] Uncertainties: see also comment under 3.3.2

(eq. 2)

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

With:

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

So, in case the available noise exposure distribution of the study area ranges from 50 to 70 dB L_{night} (which is often the case with END noise maps), the summation is restricted for the population adults between 50 and 70 dB (L_{night}).

3.5.2 *The number of highly annoyed people*

The number of adults (persons aged 18 years or older)[11] with high annoyance for noise from a specific source within a specific noise category can be calculated with the following equation:

(eq. 3)

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

Where:

$n_{high\ annoyance}(L_{den})$: 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 derived from national, regional or local statistics
$\int_{annoyance}(L_{den}$, source): source-specific exposure-response equation for high annoyance

The total number of adults with high annoyance from a specific source can be calculated by summing the number of highly annoyed persons per noise category.

(eq.4)

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

Where:

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

So, in case the available noise exposure distribution of the study area ranges from 55 to 75 dB L_{DEN} (which is often the case with END noise maps), the summation is restricted for the population adults between 55 and 75 dB (L_{den}).

[11] Uncertainties: see also comment under 3.3.2

3.5.3 *Number of children with comprehensive reading impairment.*

The number of children 7-17 years old with a reading impairment in the study area can be calculated for aircraft noise per noise exposure category (L_{DEN}) with the following equation:

(eq.5)

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

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})*
$f_{7\text{-}17yr}$: *Fraction children 7-17 year old in the study area*
$\int_{reading}(L_{den}, aircraft)$: *Exposure-response equation for reading impairment associated with aircraft noise*

The total number of children 7-17 years old with a reading impairment in the study area can be calculated by summing up the number of children with reading impairment per noise exposure category:

(eq.6)

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

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:

(eq. 7)

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

With
$n_{inhab}(L_{den})$: *Number of inhabitants per aircraft noise exposure category (L_{den}*
$f_{7\text{-}17yr}$ *Fraction children 7-17 year old in the study area*
$f_{baseline}$: *Baseline prevalence (= 0.1)*

3.5.4 *Incidence of and mortality due to Coronary Heart Disease*

The number affected in relation to noise exposure is expressed in two measures:

- The incidence
- The cause-specific mortality

The NafP due to a risk factor, is often estimated by making use of the population attributable fraction (PAF): the proportional reduction in population disease or mortality that would occur if exposure to a risk factor was reduced to an alternative ideal exposure scenario.[13] The PAF can be calculated with the following equation:

(eq. 8):

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

Where:

$f_{inhab}(L_{den})$: The fraction of residents per dB (L_{den}) of the study area (neighbourhood, city, region, country);
$f_{inhab}(L_{den}, alt)$: The fraction of residents per dB (L_{den}) of the study area in an alternative, ideal exposure scenario
$RR(L_{den})$: The Relative Risk (RR) at exposure level L_{den}.

If we assume that an ideal exposure scenario does not lead to an excess risk (RR = 1), equation 8 can be written as follows:

(eq. 9)

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

The RRs per 10 dB (Lden) presented in table 3.5 and the recommended threshold in section 3.4.4.1 should be used to calculate the RR for a certain exposure level (RR(LDEN)):

- For the incidence of coronary heart disease a RR of 1.08 per 10 dB L_{den} should be used; for mortality due to coronary heart disease a RR of 1.05 per 10 dB L_{den} should be applied.
- In both cases a threshold of 53 dB (L_{den}) is assumed.

The result are two PAFs: one PAF for the incidence of coronary heart disease due to noise ($PAF_{CHDincidence}$) and one PAF for mortality due to coronary heart disease due to noise
($PAF_{CHD\ mortality}$).

In the next step, the number of attributable cases per year can be calculated as follows:
(eq. 10)

$$PAF * incidence$$

With:
PAF: Population attributive fraction for the incidence of coronary heart disease due to noise or for mortality due to to coronary heart disease due to noise
Incidence : Incidence of CHD heart disease or mortality due to CHDper year for the study area i.e. the total number of incident cases with coronary heart disease in the study area or the total number of deaths due to coronary heart disease in the area

The PAFs calculated by means of equation 9 are input for equation 10 in order to calculate the number of persons with a coronary heart disease per year attributable to noise and the number of deaths due to coronary heart disease due to noise. A small note with regard to the incidence mentioned in equation 10: This means the total number of incident cases with coronary heart disease in the study area or the total number of deaths due to coronary heart disease in the area. However, the incidence of a disease or mortality is often presented as a rate (e.g. the number of deaths per 100.000 persons). In that case the number of inhabitants should be used to assess the total number of incident cases with coronary heart disease in the study area or the total number of deaths due to coronary heart disease in the area.
For example, the mortality rate due to coronary heart disease in a certain area where 308,952 people live is 2,738 per 100,000. The total number of deaths due to coronary heart disease can be estimated by multiplying the mortality rate (2,738/100,000) with the total number of people in the study area (308,952). This is equal to 8,460 deaths

3.6 HIA Method 1: Summarizing the NafPs

The number of affected people (NafP) is calculated separately for each outcome and noise source that is included in the HIA. For this purpose, the formulas presented in section 3.5are to be used to assess:

- the number of highly sleep disturbed people (HSD; eq. 1, 2);
- the number of highly annoyed people (HA; eq. 3, 4);
- for aircraft noise, only: the number of 7-17 years old children with a reading impairment (eq. 5-7);
- the number of people with coronary heart disease per year attributable to noise (eq. 9, 10) ;
- the number of deaths due to coronary heart diseases attributable to noise (eq. 9, 10)

In principle, for each noise source there are three ways of how you can process the estimated numbers, using NafPs for mapping the noise-attributable health status and/or to prioritise and evaluate noise action plans (NAP):

1. Consider NafP for each outcome separately.
2. Sum-up the outcome-specific NafPs to a *total* health-related NafP.
3. Rank the outcome-specific NafPs in a stepwise manner.

Option 1 was extensively described in section 3.5. One could consider all the outcomes for which guidance was given in section 3.5. Especially, when the aim of an HIA is to give insight into the impact of environmental noise on the health and well-being of residents living in the study area, this is a good option. But in other cases it is better to focus on those outcomes that are relevant for the (policy) question that you need to answer, and the context. Preferably, these choices are made in close collaboration with the stakeholders involved and at the start of the HIA process.

Option 2: summing-up the outcome-specific NafPs into total NafP just like that, is conceptually seen as difficult. It would mean that you add up annoyed people with deaths due to coronary disease and children with

reading impairment. A solution could be to produce some kind of total NAfP, weighting for the severity of the effect. But that would be quite comparable to the procedure of DALY calculation. Especially, if you would take the same disability weights (DW) that are being used for the DALY calculation for high annoyance and high sleep disturbance (section 3.8). However, at the moment the weights for annoyance and sleep disturbance are still under debate. Furthermore, there is a problem for CHD and reading impairment in children. At the moment there are no clear cut weights available for these effects. An extra problem that arises when summing up the outcome specific NafPs, is the problem of double counting as was also described in section 2.3.4. For the evaluation of the outcome-specific NAfPs (option 1) this would not pose a problem.
Also , when applying the sum of NafPs in case of the evaluation of interventions it could indicate different impacts, as the sum might be based on different outcomes. For example, traffic restrictions at night-time might considerably reduce sleep disturbance but lead to an increase in annoyance in the daytime. Thus, in this case the sums of NafPs before and after the imposement of the night-time traffic restriction would not reflect appropriately what really has happened in terms of changes in sleep disturbance and annoyance. In principle, most problems described here also apply to the DALY calculation. However, the main advantage of a DALY is that it allows to compare the health impact of noise with the health impact of other environmental or social burden using the same unit.

Option 3: Examples of a stepwise ranking procedure using outcome-specific NafPs for the evaluation of NAPs are available from a HIA which was carried out in the region around the airport Berlin-Brandenburg. ACCON[16] proposed a stepwise procedure of using the number of noise attributable cases of CHD and the number of highly noise annoyed and sleep disturbed people around the airport for the assessment of the impact of noise from multiple sources. The estimations were done for different noise scenarios in order to prioritise actions. In a first step, the impact of noise scenarios on cases of CHD was assessed. Those scenarios obtained priority which could considerably reduce the number of CHD cases. The preference of the remaining scenarios would then be assessed by estimating stepwise their impact on sleep disturbance and then on noise annoyance. Similarly, Eggert et al.[17] used the method introduced by ACCON in order to assess the noise impact of different flight procedures on annoyance, sleep-disturbances and cardio-vascular health risks. Those flight routes were preferred from a noise impact perspective, which first reduced the number of CHD cases, second, the number of highly sleep disturbed people and, finally, the number of highly annoyed people. Whilst this procedure allows to consider the outcomes separately, it includes an indirect ranking of the outcomes with regard to severity in defining which outcome is taken at which step to evaluate the preference of different noise scenarios from a noise-health perspective. This ranking of outcomes is as arbitrary a process as the DW. However, it is somewhat more transparent than the calculation of a single total health indicator. Note, that the stepwise procedure of calculating outcome-specific NafPs in a given sequence is reasonable for a relative evaluation, i.e. to compare noise scenarios against a baseline scenario. For the assessment of the status quo of the health impact of environmental noise in a given area it doesn't make sense.

3.7 HIA Method 2: Calculation of disability-adjusted life years

DALY combines the time lived with disability and the time lost due to premature mortality in one measure:

(eq. 11): $DALY = YLL + YLD$

With
DALY: Disability-adjusted Life Year
YLL: Years of Life Lost due to premature mortality
YLD: Years lived with Disability

The general methodology for environmental burden of disease calculations as carried out in the Global Burden of Disease (GBD) project [20-22] and EBoDE-project[23] follows the comparative Assessment Approach.[24] In order to calculate the environmental burden of disease, information about population exposure, exposure-response functions, and the DALYs lost to disease for the risk factor of interest (or other epidemiological information, such as mortality rates or disease incidence, if DALYs are not available) are required. Subsequently, the environmental burden of disease is calculated as follows: Population exposure data and Relative Risks (RR) derived from epidemiological data (e.g. meta-analyses), are combined into an impact fraction, which is applied to the disease estimates. This fraction is applied to the Global Burden of Disease figures or national burden of disease data. In the GBD project only diseases with an ICD-code are included. Practically this would mean that in relation to environmental noise only coronary heart disease (and when possible stroke) are included in the DALY calculation. In order to calculate the years lived with disability attributable to noise (YLD) and the years of life lost due to premature mortality attributable to noise (YLL), the Population Attributable Fraction (PAF) is used. The PAF for the study area can be calculated by means of equation 9.

In the next step, the number of attributable cases per year can be calculated by means of equation 12.

(Eq. 12):

$$PAF * incidence_{YLL\ or\ YLD}$$

With:
IncidenceYLL or YLD: the incidence of disease characteristic (YLL or YLD) per year in the study area i.e. the total number of YLL due to CHD in the study area or the total number of YLD due to coronary heart disease in the area

A note with regard to the incidence mentioned in equation 12: We mean with this the total number of YLLs due to CHD in the study area or the total number of YLDs due to coronary heart disease in the area. However, the number of YLLs or YLDs is often presented as a rate (e.g. the number of YLLs per 100.000 persons). In that case the number of inhabitants should be used to assess the total number of YLLs due

coronary heart disease in the study area or the total number YLDs due to coronary heart disease in the area.
Using this information the total number of YLL per 100,000, the number of years lost due to premature mortality per year due to coronary heart disease in the study area can be calculated per noise exposure category with the following equation:

(Eq. 13):

$$YLL_{study\ area} = PAF_{CHDmortality} * 100{,}000 * YLL_{CHD} * N_{inhab}$$

With:

$PAF_{CHDmortality}$: Population Attributable Fraction calculated by means of equation 9, using the recommended RR per 10 dB for the association between noise and mortality due to coronary heart disease and a threshold of 53 dB (L_{DEN})

YLL_{CHD}: The number of Years of Life Lost due to premature mortality due to coronary heart disease per 100,000 persons

N_{inhab}: The number of inhabitants in the study area

When using the total number of YLD per 100,000 persons, the number of years lived with disability (YLD) per year due to CHD in the study area can be calculated in a similar way:

(Eq. 14):

$$YLD_{study\ area} = PAF_{CHDincidence} * 100{,}000 * YLD_{CHD} * N_{inhab}$$

With:

$PAF_{CHDincidence}$: Population Attributable Fraction calculated by means of equation 9, using the recommended RR per 10 dB for the association between noise and the incidence of coronary heart disease and a threshold of 53 dB (L_{DEN})

YLD_{CHD}: The number of Years of Life lived with Disability due to coronary heart disease per 100,000 persons

N_{inhab}: The number of inhabitants in the study area

When adding up the attributable number of YLL with the attributable number of YLD, the attributable number of DALYs can be calculated.

(Eq. 15.)

$$DALY_{study\ area} = YLL_{study\ area} + YLD_{study\ area}$$

Following the GBD methodology and concepts, the DALY attributable to noise would now only include CHD. However in the context of noise and health there are ample arguments to also include high annoyance and/or high sleep disturbance (see paragraph 3.8).

Furthermore, it should be noted that as part of the WHO estimate of the burden of disease due to environmental noise[18], the burden of disease due to coronary heart disease attributable to noise, is calculated in slightly different way. In the WHO calculations, the number of people with a coronary heart disease due to noise was combined with a duration (1 yr) and a disability weight.

3.8 In – or exclusion of Annoyance and sleep disturbance in DALY calculation

While both high sleep disturbance and high annoyance were part of the WHO estimate of the burden of disease due to environmental noise [18], a later document of WHO excluded annoyance and included high sleep disturbance using the ICD code for insomnia. [23] Whether it is better or not to include high annoyance and/or high sleep disturbance in the calculation of the DALY depends on the aim of a HIA and the perspective from which one considers noise and health. In the literature several arguments can be found why annoyance might not qualify as a health endpoint in DALY calculations. Of these arguments the most prominent is that annoyance does not have an ICD9 or ICD10 code. [20, 21] However, there are many arguments to include annoyance, as a very important end point in itself and a determinant of stress related long term effects. But when it is decided to include high annoyance and high sleep disturbance in the DALY calculations, one has to be aware that the resulting DALYs cannot necessarily be compared with DALYs calculated according to the new GBD method, which currently does not include high annoyance nor high sleep disturbance.

3.8.1 High Sleep disturbance

The WHO report on the Burden of Disease of Noise[18] indicates that noise–induced sleep disturbance is not the same as primary insomnia, but that their severity might be comparable. From the results of a number of studies [18,26,27,28,29,30] into the severity of sleep disturbance a disability weight (DW) of 0.07 was derived at the time (2011). Since then the methodology of the assessment of DWs for burden of disease studies has been improved and standardised. In 2015 a study was published with DWs for Europe for a set of 255 health states among a representative population of about 30,000 people from four European countries [31]. For insomnia a DW of 0.023 was estimated with a confidence interval of 0.017 to 0.028. In the WHO report a Swiss study [29] 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 l on average less serious than primary insomnia and 11 of the 14 considered sleep disturbance less severe than sleep apnoea. 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). Unfortunately the mean ratio for sleep apnoea is not mentioned, but this results is in line with the higher disability weight for apnoea than for primary insomnia of Haagsma et al.
Based on these results, a DW for highly sleep disturbed of 0.0175 is recommended (0.63 to 0.90 times the disability weight of primary insomnia).

A DW of 0.0175 is recommended in the YLD calculations for high sleep disturbance.[12]

3.8.2 *High Annoyance*

Given the discussion above, it can be questioned whether high annoyance should be included in burden of disease calculations, especially in those cases where the aim is to compare the BoD from different environmental exposures like air pollution. However, in the context of END for which this methodology is developed this is **not** the case. When used within the noise field to obtain an estimate of the total impact of noise or when comparing the impact before and after an intervention (NAP) there are good arguments to include high annoyance.[13] Given the limited number of studies on a DW for annoyance, and the sensitivity of the environmental burden attributed to noise annoyance for small changes in DW, a tentative DW of 0.02 was proposed by the WHO[1] with a relatively large uncertainty interval (0.01–0.12). These values are based on earlier work. [25, 26, 27 28, 29, 30] Based on these data and on the latest insights regarding disability weights as derived for sleep disturbance and insomnia [29, 31] a "conservative approach" is taken, by giving cases with high annoyance a DW of 0.01 for the estimation of burden in terms of DALYs, because high annoyance can be considered as less severe than high sleep disturbance.

When **excluding** annoyance it is recommended that the number of DALYs for high annoyance is estimated to be 0.

When **including** annoyance it is recommended to use 0.01 as ad-interim DW in the YLD calculations for high annoyance.

[12] In Chapter 4 the severity weight used was rounded up t 0.02

[13] In the example (Chapter 4) the effect of in or excluding annoyance is illustrated

3.9 References chapter 3

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4 Guidance Document part C: Practical examples of HIA

4.1 Introduction to the example of Düsseldorf

For the City of Düsseldorf, Germany, the health impacts of environmental noise were calculated on the basis of noise maps of the 3rd round (in 2017). The following indices were calculated for transportation noise (railway, road traffic, and aircraft noise):

- NafP by environmental noise
- DALYs, i.e. the Disability-Adjusted Live Years related to environmental noise

The HIA calculations were carried out for the following two key questions:

1. What is the status quo of the health impact of environmental noise (in the following focused on transportation noise) in Düsseldorf?
2. What are the impacts of selected noise actions on health?

In relation to noise from road, rail and aircraft noise, we have calculated the number of highly annoyed people, the number of highly sleep disturbed people, the number of people with a CHD per year attributable to noise and the number of deaths due to CHD attributable to noise. In relation to aircraft noise exposure we also assessed the number of children with reading impairment. Also DALY calculations according to the Global Burden of Disease method[1] were performed excluding high noise annoyance and sleep disturbance as health outcomes (DALY I) and compared to calculations which did include high annoyance and high sleep disturbance.

The HIA assessments were conducted for the current state of transportation noise exposure in the City of Düsseldorf and for the city district Düsseldorf-Bilk before and after the simulated implementation of three different noise abatement actions.

For these calculations, several data were needed (see Guideline Part B, 3.1.2). The HIA consisted of several steps. In the following we demonstrate how we obtained our input data and we demonstrate/describe the issues that we had to overcome when carrying out this HIA. But first we begin with a short description of the study areas of Dusseldorf and Dusseldorf-Bilk.

4.2 The study areas Düsseldorf

The area for which noise calculations have been made within the frame of the 3rd round of the noise mapping according to the EU directive for environmental noise [2] (EU directive 2002/49/EG), the City of Düsseldorf, has 635,704 inhabitants. Of these, 537,631 residents are adults, i.e. 18 years and older (85%).

For one city district, Düsseldorf-Bilk (compare Figure 4.1), the Environment Agency of Düsseldorf (EAD) calculated the impact of three simulated source-specific noise abatement actions on changes in the number of exposed residents. The actions are:

1. Road traffic noise: Noise reducing road surfaces
2. Railway noise: Green tech rail profiles
3. Road traffic noise: Speed Limit 30 km/h (as compared to 50 km/h)

Note, that in Germany railway noise includes noise from long-distance and regional trains as well as local rail traffic such as trams. The intervention 'green tech rail profiles' refer to tramway noise, and, thus, is regarded here as a (local) railway noise intervention.

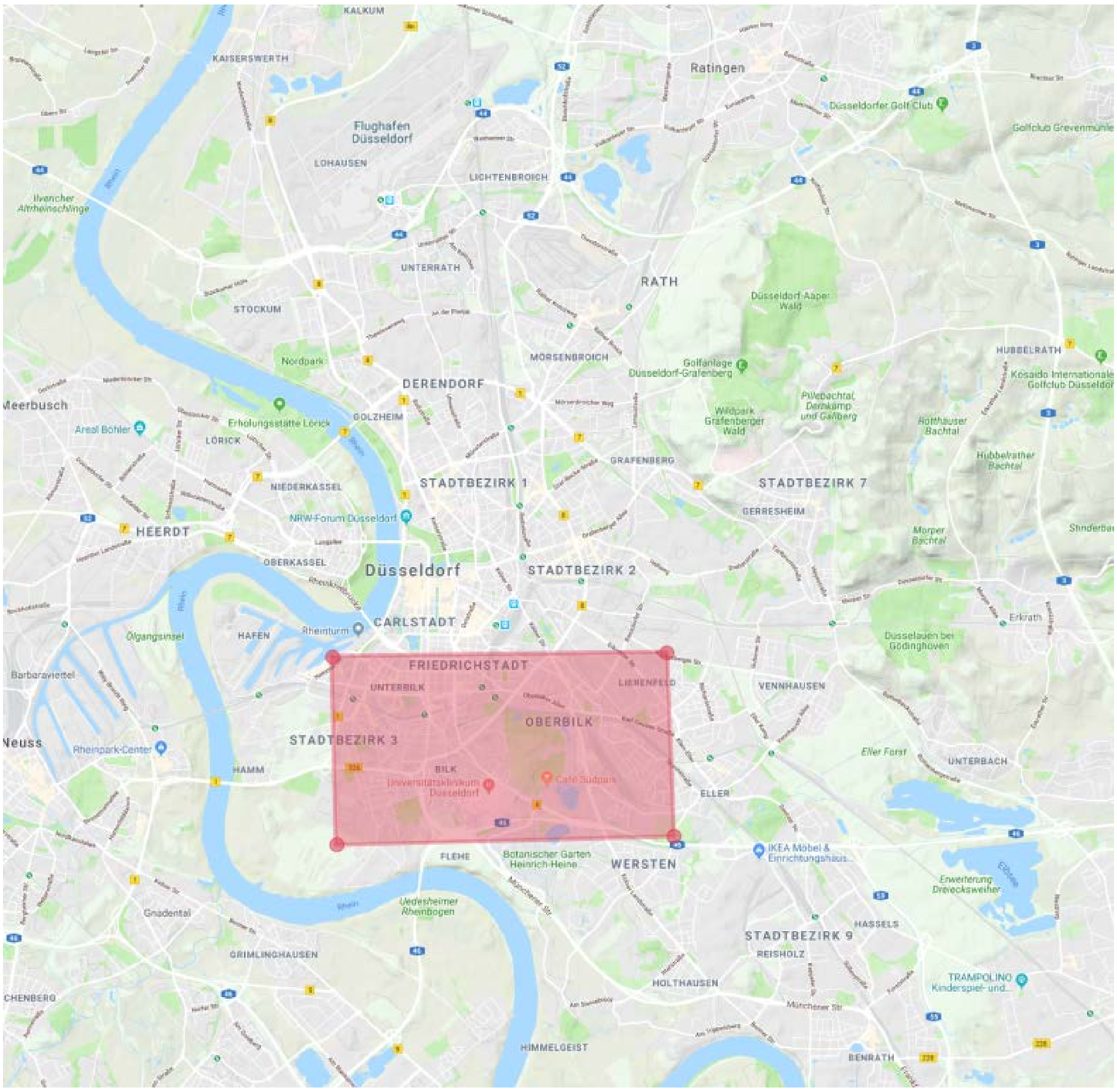

Figure 4.1: Crude representation of the estimated location of Bilk in Düsseldorf. Note: The observation area consists of three social environments, which can broadly be summed up as: Oberbilk, Unterbilk and Bilk.

Figure 4.2 depicts the noise maps for the City of Düsseldorf. Figure 4.3 presents the noise maps for the current emissions in Düsseldorf-Bilk before the simulated implementation of noise actions.

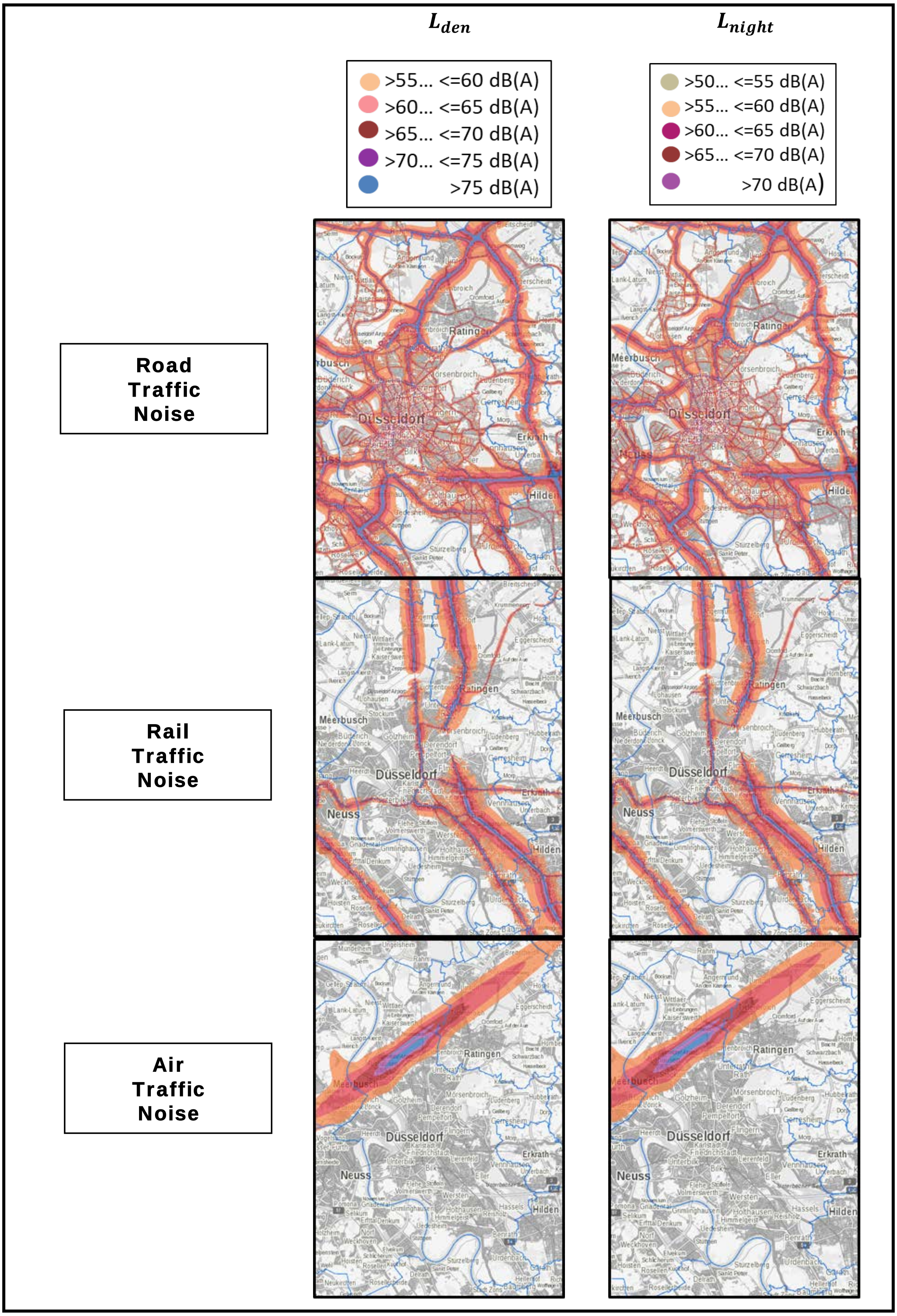

Figure 4.2: Noise Maps for the whole City of Düsseldorf

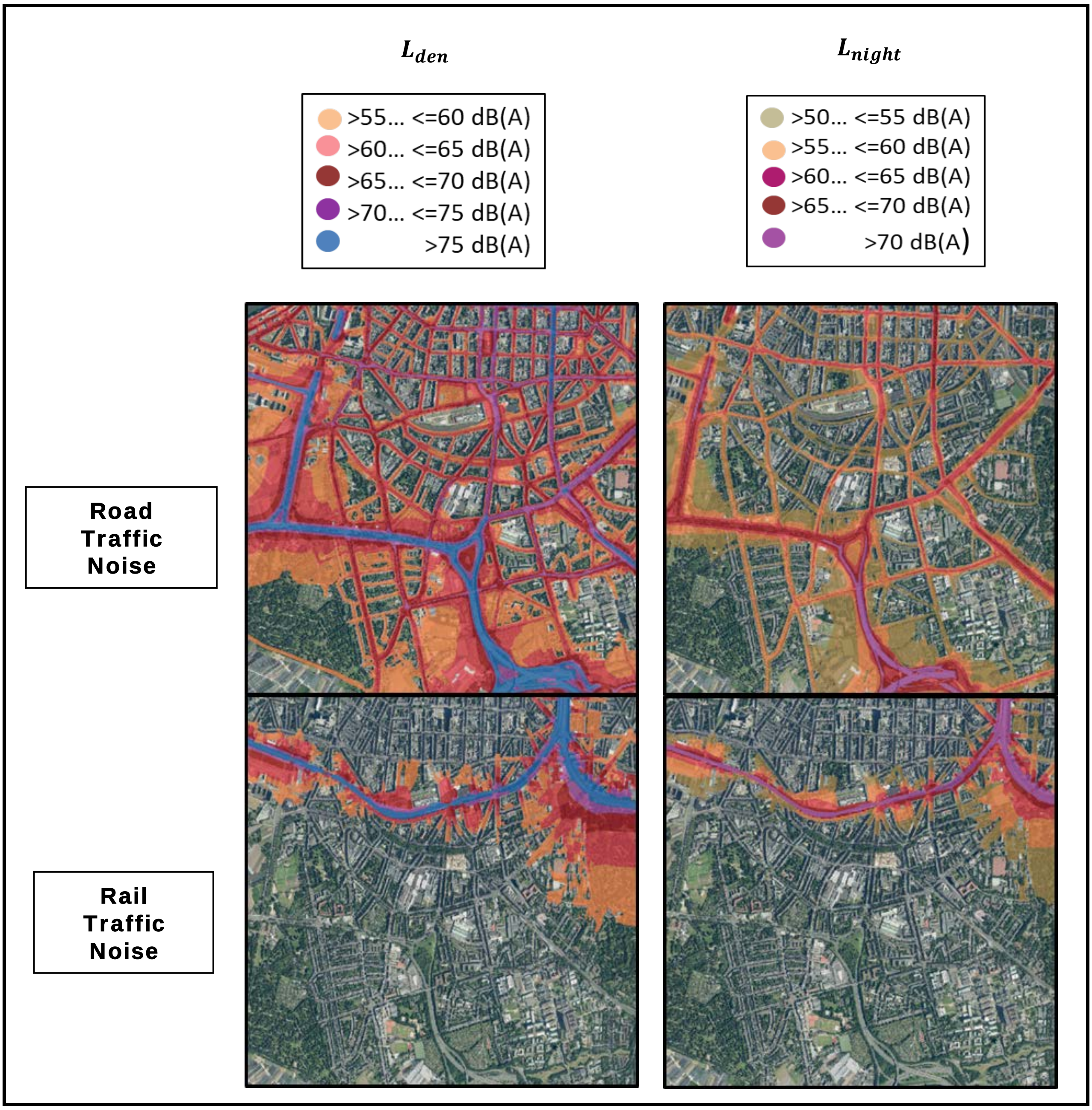

Figure 4.3: Noise maps for Düsseldorf Bilk. As there are no recorded aircraft noise emissions over this particular area, we resigned from displaying aircraft noise sources.

4.3 Preparing the quantitative HIA

4.3.1 Input data

The following inputs were obtained for the HIA assessments (see Guideline Part B, 3.1.2):

1. **The fraction of residents per noise category of the study area**
   By linking noise maps that were created in the framework of the EU Directive 2002/49/EG for the 3rd round in 2017, to the home addresses of the residents of Dusseldorf, the (EAD) provided us with population-exposure distributions. for aircraft, road traffic

and railway noise. Numbers of exposed people were available in 1 dB classes of L_{den} and L_{night} , respectively. The L_{den} classes range from below 40 to 78 dB[14] for road traffic and to 90 dB for railway. The L_{night} classes include sound level categories from below 40 dB to 69 dB for road traffic and to 81 dB for railway. For aircraft data, the EAD provided the number of exposed people in 1-dB classes within the range of 45 dB to 75 dB L_{den} and to 66 dB L_{night}.[2]

2. **Demographic data of the study area**
   Demographic and social distributions have been extracted from an official report by the City of Düsseldorf.2 In particular, this includes data on age groups and gender in 2016 (2017 was not available). Data per age group was needed since the ERFs applied in this assessment had to be applied to the adult population (18 years and older)and children in the age of 7 to 17 years. Mortality data were only available for 2015, and incidence data were available for 2014 (see next section). Therefore also population data for 2014 and 2015 were obtained.
3. **Disease and mortality data valid for the study area**
   Since no local disease and mortality data were available, we obtained these data from (inter)national sources. Mortality data for coronary heart disease were extracted from the WHO Mortality database for Germany. The most recent data is from 2015. As indicator for the incidence of coronary heart diseases (CHD) we used the Hospital discharges (total). These data were obtained from the European Hospital Morbidity Database of the WHO for Germany for the year 2014. It should be noted however, that incidence data for CHD are also available. But for now we calculated with the hospital discharge rates.

   DALYs can be calculated by summing up the years lived with a disease (YLD) with the year of life lost due to premature death (YLL). Both Years of Life Lost (YLL) and YLD due to coronary heart disease were derived from the WHO Burden of Disease project for 2016.
   All diseases and mortality data refer to Germany in total. For simplification in this exemplary HIA assessment the data is assumed to be valid for Düsseldorf.
4. **Exposure response relations**
   In the guidance document (part B) it is recommended to use local ERF-data when estimating the number of highly annoyed people and/or the number of highly sleep disturbed people in the study area. Unfortunately, no reliable and valid ERF data from Düsseldorf or elsewhere from Germany were available that could be applied in this case. Therefore we decided to apply the generalised ERFs for high annoyance and high sleep disturbance that were recommended and presented in the guidance (Part B). For stroke no assessments were made (for more details see also section 4.4).

[14] Note the maps produced END show >55 dB(A) per 5 dB classes but data was available for lower levels, and per 1 dB (A)

4.4 The HIA Assessment process

4.4.1 Step 1: Choice of health outcomes (see figure 2.1)

The following health outcomes per noise source are selected according to the recommendations in Chapter 3:

For the NafPs:

- sleep disturbance: highly sleep disturbed people (%HSD)
- highly annoyance: highly annoyed people (%HA)
- children's reading impairment (for aircraft noise, only): number of reading impaired due to aircraft noise
- the risk of coronary heart diseases (CHD): The risk of the noise-attributable incidence of CHD, the risk of noise-attributable mortality due to CHD

For the DALYs the above mentioned health outcomes were taken except of the children's impairment due to aircraft noise.

4.4.2 Step 2: Exposure assessment (see figure 2.1)

First, for policy question 1 (status quo of noise situation in Düsseldorf) noise exposure data in 5 dB classed of L_{den} and L_{night} were obtained from the Environment Agency of Düsseldorf. Figure 4.4 shows an example of the obtained raw data as provided for environmental noise maps according to the END. It shows grouped noise data starting from 50 dB to 75 dB.

However, none of this data was sufficient for HIA assessment as done here, the main problem being, that 50 dB as a starting point is too high and data grouped in 5dB steps is not accurate and not sensitive enough to assess the (change in) noise emission impact on citizens appropriately.

	A	B	C	D	E	G	H	I	J	K	L	M
1	**Analysis noise mapping EU 2017 with cadnA**											
2	**City of Düsseldorf**		n=	633,478 inhabitants								
3												
4	**Road traffic**											
5	Interval		Value	Inhabitants		LDEN	Dwellings	Schools	Hospitals		exposed area	
6	from	to	**Lden**	**Lnight**								
7		50	234,068	477,774		> 55	116,118	409	162		77.64	km²
8	50	55	124,109	88,102								
9	55	60	130,132	53,697		> 65	37,732	66	41		25.51	km²
10	60	65	79,820	13,679								
11	65	70	51,692	226		> 75	30	1	0		4.94	km²
12	70	75	13,607	0								
13	75		51	0								
14			633,478	633,478								
15												

Figure 4.4: Example of obtained noise exposure data (road traffic noise) in 5 dB Lden/Lnight-classes. Source of data: Umweltamt (Environmental Agency) Düsseldorf (translated).

Next, we asked for noise data in 1 dB classes ranging from 40 dB to at least 75 dB L_{den} and L_{night}, respectively. This could be provided for transportation noise sources (road traffic, railway aircraft) and for industry/harbor (Figure 4.5).

Table 4.5: Example of obtained noise exposure data (road traffic noise) in 1 dB Lden/Lnight-classes. Source of data: Umweltamt (Environmental Agency) Düsseldorf (translated).

	A	B	C	D	E	F	G
1	Road traffic			EU noise mapping 2017		Calculation method VBEB	
2	**LDEN**				**LNight**		
3	from dB(A)	to dB(A)	Inhabitants		from dB(A)	to dB(A)	Inhabitants
4	40	41	**20,729**		40	41	**20,970**
5	41	42	**20,325**		41	42	**22,062**
6	42	43	**18,966**		42	43	**24,100**
7	43	44	**18,155**		43	44	**25,946**
8	44	45	**17,381**		44	45	**28,088**
9	45	46	**17,696**		45	46	**28,975**
10	46	47	**17,890**		46	47	**29,909**
11	47	48	**18,973**		47	48	**30,431**
12	48	49	**19,635**		48	49	**25,385**
13	49	50	**20,792**		49	50	**23,203**
14	50	51	**21,770**		50	51	**23,959**
15	51	52	**22,913**		51	52	**19,704**
16	52	53	**25,086**		52	53	**16,489**
17	53	54	**26,314**		53	54	**14,711**
18	54	55	**28,028**		54	55	**13,239**
19	55	56	**28,644**		55	56	**12,421**
20	56	57	**28,601**		56	57	**11,238**
21	57	58	**28,258**		57	58	**10,621**
22	58	59	**23,210**		58	59	**9,943**
23	59	60	**21,419**		59	60	**9,474**
24	60	61	**21,521**		60	61	**6,043**
25	61	62	**17,715**		61	62	**3,754**
26	62	63	**15,143**		62	63	**2,330**
27	63	64	**13,751**		63	64	**1,303**
28	64	65	**11,691**		64	65	**248**
29	65	66	**11,920**		65	66	**196**
30	66	67	**10,880**		66	67	**22**
31	67	68	**9,763**		67	68	**4**
32	68	69	**9,392**		68	69	**4**
33	69	70	**9,737**		69	70	**0**
34	70	71	**5,786**		70	80	**0**
35	71	72	**3,901**				
36	72	73	**2,308**				
37	73	74	**1,272**				
38	74	75	**341**				
39	75	76	**33**				
40	76	77	**13**				
41	77	78	**5**				
42	78	79	**0**				
43	79	80	**0**				
44	80	90	**0**				

For aircraft noise the EAD could not provide data below 45 dB L_{den} as aircraft noise exposure was not estimated by the City of Düsseldorf but by the environmental authority of the federal state North-Rhine Westfalia (LANUV; *Landesamt für Natur, Umwelt und Verbraucherschutz*). On request, LANUV sent us shapefiles with façade-related aircraft noise exposure information for the City of Düsseldorf. However, it was not possible to relate this information to number of exposed residents in time, so for aircraft noise the exposure data obtained from the EAD was used for the HIA.

The noise mapping for railway noise (regional, long-distance) is normally done by the EBA (*Eisenbahn Bundesamt*, German Federal Railway Agency). As EBA does not estimate the number of exposed people in 1 dB classes L_{den}/L_{night}, for the City of Düsseldorf the number of exposed inhabitants in L_{den}/L_{night} -boundaries were re-estimated by the EAD. This data, therefore, might deviate from the official EBA statistics on railway noise exposed residents.

Finally, with the available data we were able to assess a HIA for the current state in Düsseldorf as shown in table 4.3 to table 4.7.

For policy question 2 (health impact of noise actions), the EAD calculated the change in noise exposure (noise scenarios) due to two simulated noise interventions referring to road traffic noise and to one simulated intervention referring to railway noise and estimated the change in numbers of exposed persons per 1 dB $L_{\mathrm{den}}/L_{\mathrm{night}}$ category. The EAD estimated the change in exposure data not per single noise intervention but per noise source. That is, for road traffic noise the combined effect of noise reducing road surfaces and reduction of speed limit (from 50 km/h to 30 km/h) on the number of exposed people was estimated. For tramway noise the effect of the implementation of green tech rail profiles was estimated. We used this information as input data for the assessment of the health impact of noise abatement actions.

4.4.2.1 Results concerning transportation noise in Düsseldorf

Table 4.1 shows the distribution of residents over 1 dB-classes of L_{den} and L_{night}, respectively, for road traffic, railway and aircraft noise.

Table 4.2 and Figure 4.6 present the number of adult residents (18 years and older) exposed to classes of sound levels for tramway or road traffic noise before and after the simulated implementation of noise abatement actions for the city district of Düsseldorf-Bilk.

Tables 4.1 and Table 4.2 as well as Figure 4.6 combine the information from EAD about the number of exposed persons per 1 dB category in $L_{\mathrm{den}}/L_{\mathrm{night}}$ with the city-wide percentage of adults (18 years and older) obtained from the demographics report of the City of Düsseldorf .[2] As the intervention area of Düsseldorf-Bilk covers parts of several social districts for which demographic data is available for simplification the city-wide distribution in age and gender was applied to the intervention area. An alternative would have been to calculate the mean of the distribution in age and gender of the relevant social districts.

Figure 4.6 demonstrates already that the noise exposure level of most people in Dusseldorf-Bilk will not change after implementation of the proposed interventions. Later-on we will demonstrate what that means for the estimated health gain (to be estimated in the next steps/sections).

Table 4.1: Number of residents of the City of Düsseldorf exposed to transportation noise exposure

1-dB sound level class L_{den}/L_{night}			Road traffic				Railway (tramway, regional, long-distance)				Aircraft			
			L_{den}		L_{night}		L_{den}		L_{night}		L_{den}		L_{night}	
From	To	M	Total N	N ≥ 18yrs	Total N	N ≥ 18yrs	Total N	N ≥ 18yrs	Total N	N ≥ 18yrs	Total N	N ≥ 18yrs	Total N	N ≥ 18yrs
	40		45751	38693	220932	186848	9125	7718	250744	212061	528085	446615	626819	530117
40	41	40.5	20729	17531	20970	17735	38367	32448	31446	26595				
41	42	41.5	20325	17190	22062	18658	35506	30028	31200	26386				
42	43	42.5	18966	16040	24100	20382	33554	28378	31324	26492				
43	44	43.5	18155	15354	25946	21943	31993	27058	29396	24861				
44	45	44.5	17381	14699	28088	23754	31609	26733	27626	23364				
45	46	45.5	17696	14966	28975	24505	32195	27228	25283	21382	14070	11899	2136	1806
46	47	46.5	17890	15130	29909	25295	31294	26466	23669	20017	20962	17728	1652	1397
47	48	47.5	18973	16046	30431	25736	31339	26504	22913	19378	18321	15495	1095	926
48	49	48.5	19635	16606	25385	21469	32364	27371	21076	17825	7227	6112	723	611
49	50	49.5	20792	17585	23203	19624	31835	26924	18523	15666	7520	6360	336	284
50	51	50.5	21770	18411	23959	20262	29716	25131	15513	13120	7715	6525	215	182
51	52	51.5	22913	19378	19704	16664	27568	23315	14194	12005	7639	6460	329	278
52	53	52.5	25086	21216	16489	13945	26194	22153	12612	10666	7888	6671	223	189
53	54	53.5	26314	22254	14711	12441	24848	21014	10937	9250	4120	3484	218	184
54	55	54.5	28028	23704	13239	11197	24116	20396	10401	8796	2465	2085	200	169
55	56	55.5	28644	24225	12421	10505	21415	18111	9805	8292	2250	1903	196	166
56	57	56.5	28601	24188	11238	9504	18599	15730	8720	7374	1196	1011	126	107
57	58	57.5	28258	23899	10621	8982	15464	13078	8864	7497	616	521	117	99
58	59	58.5	23210	19629	9943	8409	13767	11643	6983	5906	354	299	75	63
59	60	59.5	21419	18114	9474	8013	12435	10516	6495	5493	300	254	97	82
60	61	60.5	21521	18201	6043	5111	10733	9077	5153	4358	726	614	207	175
61	62	61.5	17715	14982	3754	3175	9654	8164	3769	3187	769	650	215	182
62	63	62.5	15143	12807	2330	1971	8163	6903	2611	2208	719	608	225	190
63	64	63.5	13751	11629	1303	1102	8485	7176	1740	1471	510	431	278	235
64	65	64.5	11691	9887	248	210	8328	7043	1251	1058	444	376	189	160
65	66	65.5	11920	10081	196	166	7474	6321	901	762	168	142	33	28

1-dB sound level class L_{den}/L_{night}			Road traffic				Railway (tramway, regional, long-distance)				Aircraft			
			L_{den}		L_{night}		L_{den}		L_{night}		L_{den}		L_{night}	
From	To	M	Total N	N ≥ 18yrs	Total N	N ≥ 18yrs	Total N	N ≥ 18yrs	Total N	N ≥ 18yrs	Total N	N ≥ 18yrs	Total N	N ≥ 18yrs
66	67	66.5	10880	9201	22	19	7336	6204	711	601	100	85		
67	68	67.5	9763	8257	4	3	5892	4983	660	558	138	117		
68	69	68.5	9392	7943	4	4	5220	4414	442	374	157	133		
69	70	69.5	9737	8235			3301	2792	206	174	264	223		
70	71	70.5	5786	4893			2367	2002	143	121	262	222		
71	72	71.5	3901	3299			1610	1362	128	108	217	184		
72	73	72.5	2308	1952			1018	861	159	134	290	245		
73	74	73.5	1272	1075			748	633	45	38	208	176		
74	75	74.5	341	288			623	527	28	23	4	3		
75	76	75.5	33	28			501	424	12	10				
76	77	76.5	13	11			304	257	4	3				
77	78	77.5	5	4			167	141	1	1				
78	79	78.5					153	129	3	3				
79	80	79.5					86	72	9	7				
80	81	80.5					145	123	10	8				
81	82	81.5					38	32						
82	83	82.5					26	22						
83	84	83.5					6	5						
84	85	84.5					4	3						
85	90	87.5					22	19						
Sum			**635704**	**537631**	**635704**	**537631**	**635704**	**537631**	**635704**	**537631**	**635704**	**537631**	**635704**	**537631**

Table 4.2: Number of exposed adult residents of the city district Düsseldorf-Bilk before/after simulated noise abatement actions

1-dB sound level class L_{den}/L_{night}			Road traffic: Noise reducing road surfaces and speed limit reduction				Tramway: Green tech rail profiles			
			L_{den}		L_{night}		L_{den}		L_{night}	
From	To	M	N before	N after	N before	N after	N before	N after	N before	N after
	40		220	730	6433	6592	1012	1214	5530	5785
40	41	40.5	420	1028	295	255	385	500	875	909
41	42	41.5	888	873	250	239	418	419	773	777
42	43	42.5	868	841	261	265	534	493	684	632
43	44	43.5	882	759	223	174	606	643	654	529
44	45	44.5	923	713	181	183	670	718	393	390
45	46	45.5	770	606	126	153	816	834	281	246
46	47	46.5	577	411	187	223	868	751	239	234
47	48	47.5	420	290	160	167	866	857	247	249
48	49	48.5	351	285	131	183	773	795	175	303
49	50	49.5	300	219	224	219	713	727	139	188
50	51	50.5	250	261	512	557	686	569	148	173
51	52	51.5	254	222	313	547	413	407	268	251
52	53	52.5	225	191	420	458	333	247	327	254
53	54	53.5	191	165	791	564	237	234	247	284
54	55	54.5	144	171	338	206	271	251	129	101
55	56	55.5	139	168	359	352	189	207	133	116
56	57	56.5	185	191	262	274	128	208	219	160
57	58	57.5	155	205	233	430	99	187	268	215
58	59	58.5	148	153	71	220	212	249	314	373
59	60	59.5	341	357	163	288	193	186	179	254
60	61	60.5	412	430	314	333	299	237	158	230
61	62	61.5	326	585	142	140	221	227	174	185
62	63	62.5	407	423	241	2	191	174	188	61
63	64	63.5	703	484	308	3	150	144	164	9

1-dB sound level class L_{den}/L_{night}			Road traffic: Noise reducing road surfaces and speed limit reduction				Tramway: Green tech rail profiles			
			L_{den}		L_{night}		L_{den}		L_{night}	
From	To	M	N before	N after	N before	N after	N before	N after	N before	N after
64	65	64.5	350	227	90	0	172	161	18	13
65	66	65.5	330	330	1	0	215	125	40	40
66	67	66.5	295	307			325	316	59	59
67	68	67.5	226	415			184	298	6	6
68	69	68.5	77	213			144	266		
69	70	69.5	127	239			206	217		
70	71	70.5	285	420			192	43		
71	72	71.5	185	109			147	15		
72	73	72.5	223	6			67	17		
73	74	73.5	351	3			79	79		
74	75	74.5	81	0			12	12		
75	76	75.5	0	0			0	0		
76	77	76.5	0				0	0		
77	78	77.5	0				0	0		
78	79	78,5	0				0	0		
79	80	79,5	0				0	0		
80	90	80,5	0				0	0		
Sum			**13027**	**13027**	**13027**	**13027**	**13027**	**13027**	**13027**	**13027**

Road traffic:
Noise reducing road surfaces
and speed limit reduction

Tramway:
Green tech rail profiles

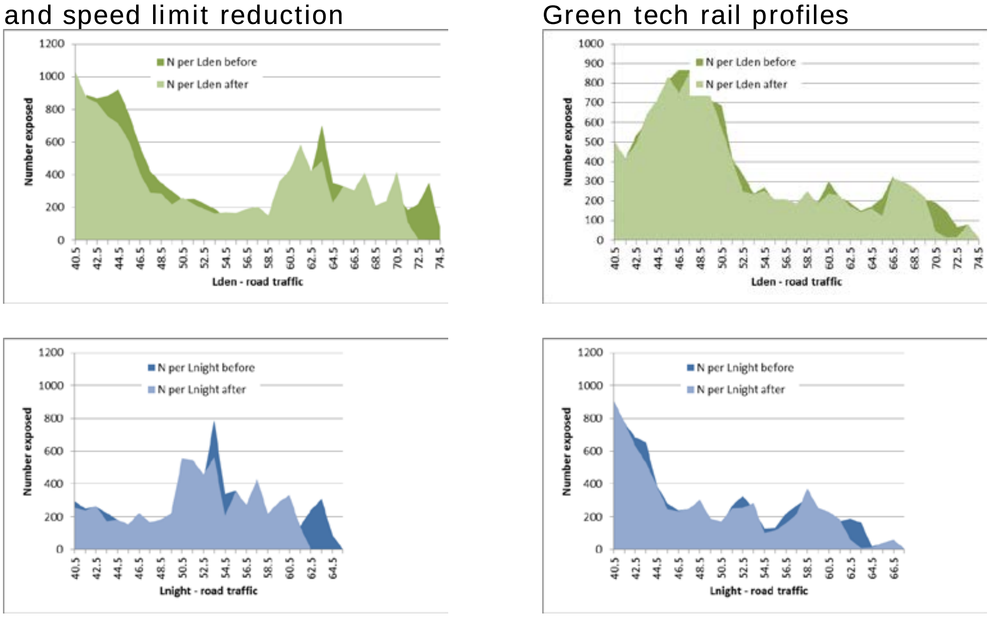

Figure 4.6: Number of exposed adult residents of the city district Düsseldorf-Bilk before/after simulated noise abatement indicators

4.4.3 *Step 3: Choice of exposure response functions (see figure 2.1)*

As no local exposure-response functions for transportation noise annoyance were available for Düsseldorf we looked whether other German data on the impact of transportation noise on annoyance could be obtained and adapted to Düsseldorf. One of the latest survey on annoyance due to aircraft, road traffic, and railway noise is the NORAH (Noise-Related Annoyance, Cognition, and Health) study on annoyance and quality of life.[3] However, it was found that the ERFs differ between the regions around the airports studied in NORAH (Frankfurt, Berlin, Cologne, Stuttgart). Thus it was decided to take the generalised ERFS for the percentage of highly annoyed persons (%HA) from the latest WHO evidence reviews for environmental noise annoyance[4]. These functions are presented in Table 3.3 in section 3.4.2.

4.5 Estimation of the NafP by transportation noise -HIA method 1 Step 4 (see figure 2.1)

The estimation of the status quo (policy question 1) of the NafP by transportation noise has been done for each source and outcome. For noise annoyance the exposure-response relation for the percentage of highly annoyed people was multiplied with the number of exposed residents for each 1 dB-L_{den} class and these products summed up across sound level classes to the total number of highly annoyed people. For this, the equations 3 and 4 in 3.5.2 were used.

In a similar way as for high annoyance, the number of highly sleep disturbed people was assessed by means of (1) multiplying the exposure-response relation for the percentage of highly sleep disturbed people with the number of exposed adults and (2) then summing up across all L_{night} classes as presented in Table 4.3 to Table 4.5, respectively (see equations 1 and 2 in 3.5.1). The ERFs for the percentage of highly sleep disturbed people (%HSD) from the WHO evidence reviews for the impact of environmental noise on sleep were used (here: self-reported noise source-specific sleep disturbance).[6] These functions are presented in Table 3.2 in Chapter 3.4.1 for the percentage of highly sleep disturbed persons. For aircraft noise the number of children in Düsseldorf with reading impairment due to aircraft noise was estimated using equations 5 to 8 in Chapter 3.5.3. The ERF presented in Figure 3.5 and Table 3.4 of Chapter 3.4.3 were used for the estimation. Information on the average number of children per 1 dB sound level class ($L_{\mathrm{den}}/L_{\mathrm{night}}$) was obtained by multiplying the total number of persons per sound level class with the fraction of 7 to 17 years old children living in the City of Düsseldorf according to the demographics report of Düsseldorf.[2]Results for the number of highly annoyed and sleep disturbed persons can be found in Tables 4.4 to 4.6. Results for children's reading impairment due to aircraft noise can be found in Table 4.6.

Table 4.3: Estimated number of highly noise annoyed and sleep disturbed people due to road traffic noise in Düsseldorf

Sound level class (L_{den}/L_{night})			Road traffic					
From	To	M	exposed to L_{den}	HA	% HA	exposed to L_{night}	HSD	% HSD
	40		38693	0	0.00%	186848	0	0.00%
40	41	40.5	17531	1546	8.82%	17735	0	0.00%
41	42	41.5	17190	1462	8.51%	18658	0	0.00%
42	43	42.5	16040	1325	8.26%	20382	0	0.00%
43	44	43.5	15354	1242	8.09%	21943	0	0.00%
44	45	44.5	14699	1173	7.98%	23754	0	0.00%
45	46	45.5	14966	1189	7.94%	24505	744	3.04%
46	47	46.5	15130	1206	7.97%	25295	825	3.26%
47	48	47.5	16046	1295	8.07%	25736	904	3.51%
48	49	48.5	16606	1368	8.24%	21469	814	3.79%
49	50	49.5	17585	1490	8.47%	19624	803	4.09%
50	51	50.5	18411	1616	8.78%	20262	895	4.42%
51	52	51.5	19378	1773	9.15%	16664	795	4.77%
52	53	52.5	21216	2035	9.59%	13945	718	5.15%
53	54	53.5	22254	2248	10.10%	12441	690	5.55%
54	55	54.5	23704	2531	10.68%	11197	669	5.98%
55	56	55.5	24225	2743	11.32%	10505	675	6.43%
56	57	56.5	24188	2911	12.04%	9504	656	6.91%
57	58	57.5	23899	3064	12.82%	8982	665	7.41%
58	59	58.5	19629	2683	13.67%	8409	667	7.94%
59	60	59.5	18114	2643	14.59%	8013	680	8.49%
60	61	60.5	18201	2835	15.58%	5111	463	9.07%
61	62	61.5	14982	2492	16.63%	3175	307	9.67%
62	63	62.5	12807	2274	17.76%	1971	203	10.30%
63	64	63.5	11629	2204	18.95%	1102	121	10.95%
64	65	64.5	9887	1998	20.21%	210	24	11.63%
65	66	65.5	10081	2172	21.54%	166	20	12.34%
66	67	66.5	9201	2111	22.94%	19	2	13.07%
67	68	67.5	8257	2015	24.41%	3	0	13.82%
68	69	68.5	7943	2061	25.94%	4	1	14.60%
69	70	69.5	8235	2268	27.55%			
70	71	70.5	4893	1430	29.22%			
71	72	71.5	3299	1021	30.96%			
72	73	72.5	1952	639	32.77%			
73	74	73.5	1075	373	34.64%			
74	75	74.5	288	105	36.59%			
75	76	75.5	28	11	38.60%			
76	77	76.5	11	5	40.68%			
77	78	77.5	4	2	42.84%			
Sum			**537631**	**63558**	**11.82%**	**537631**	**12344**	**2.30%**

Note. HA = highly annoyed; HSD = highly sleep disturbed.

Table 4.4 Estimated number of highly noise annoyed and sleep disturbed people due to railway noise in Düsseldorf

Sound level class (L_{den}/L_{night})			Railway					
From	To	M	exposed to L_{den}	HA	% HA	exposed to L_{night}	HSD	% HSD
	40		7718	0	0.00%	212061	0	0.00%
40	41	40.5	32448	540	1.66%	26595	0	0.00%
41	42	41.5	30028	584	1.95%	26386	0	0.00%
42	43	42.5	28378	648	2.28%	26492	0	0.00%
43	44	43.5	27058	725	2.68%	24861	0	0.00%
44	45	44.5	26733	837	3.13%	23364	0	0.00%
45	46	45.5	27228	992	3.64%	21382	761	0.00%
46	47	46.5	26466	1114	4.21%	20017	795	3.56%
47	48	47.5	26504	1281	4.83%	19378	865	3.97%
48	49	48.5	27371	1509	5.51%	17825	897	4.46%
49	50	49.5	26924	1683	6.25%	15666	889	5.03%
50	51	50.5	25131	1771	7.05%	13120	840	5.68%
51	52	51.5	23315	1841	7.90%	12005	865	6.40%
52	53	52.5	22153	1951	8.81%	10666	863	7.21%
53	54	53.5	21014	2053	9.77%	9250	837	8.09%
54	55	54.5	20396	2201	10.79%	8796	887	9.05%
55	56	55.5	18111	2150	11.87%	8292	929	10.08%
56	57	56.5	15730	2046	13.01%	7374	914	11.20%
57	58	57.5	13078	1858	14.20%	7497	1024	12.39%
58	59	58.5	11643	1799	15.45%	5906	887	13.67%
59	60	59.5	10516	1763	16.76%	5493	903	15.02%
60	61	60.5	9077	1645	18.13%	4358	782	16.44%
61	62	61.5	8164	1596	19.55%	3187	623	17.95%
62	63	62.5	6903	1452	21.03%	2208	468	19.54%
63	64	63.5	7176	1619	22.56%	1471	337	21.20%
64	65	64.5	7043	1701	24.15%	1058	262	22.94%
65	66	65.5	6321	1631	25.80%	762	203	24.76%
66	67	66.5	6204	1707	27.51%	601	172	26.66%
67	68	67.5	4983	1459	29.27%	558	171	28.63%
68	69	68.5	4414	1373	31.10%	374	123	30.69%
69	70	69.5	2792	921	32.97%	174	61	32.82%
70	71	70.5	2002	699	34.91%	121	45	35.03%
71	72	71.5	1362	503	36.90%	108	43	37.32%
72	73	72.5	861	335	38.95%	134	57	39.69%
73	74	73.5	633	260	41.05%	38	17	42.13%
74	75	74.5	527	228	43.22%	23	11	44.66%
75	76	75,5	424	193	45.44%	10	5	47.26%
76	77	76,5	257	123	47.71%	3	2	49.94%
77	78	77,5	141	71	50.05%	1	1	52.70%
78	79	78,5	129	68	52.44%	3	2	55.53%
79	80	79,5	72	40	54.88%	7	5	58.45%
80	85	82,5	123	70	57.39%	8	6	61.44%
81	82	81.5	32	17	59.95%			
82	83	82.5	22	12	62.57%			
83	84	83.5	5	3	65.24%			
84	85	84.5	3	2	67.98%			
85	90	87.5	19	14	76.52%			
Sum			**537631**	**63558**	**8.76%**	**537631**	**16551**	**3.08%**

Note. HA = highly annoyed; HSD = highly sleep disturbed.

Table 4.5 Estimated number of highly noise annoyed and sleep disturbed adult people and children with reading impairment due to aircraft noise in Düsseldorf

Sound level class (L_{den}/L_{night})			Air Traffic								
			Adults ...						Children ...		
From	To	M	exposed to L_{den}	HA	% HA	exposed to L_{night}	HSD	% HSD	exposed (7-17 years old)	with additional reading impair-ment due to aircraft noise	% impaired
	40		446615	19592	4.39%	530117	0	0.00%	62210	0	0,00%
40	41	40,5									
41	42	41,5									
42	43	42,5									
43	44	43,5									
44	45	44,5									
45	46	45,5	11899	1214	10.20%	1806	0	0.00%	1377	138	10.00%
46	47	46,5	17728	2106	11.88%	1397	0	0.00%	2051	205	10.00%
47	48	47,5	15495	2103	13.57%	926	0	0.00%	1793	179	10.00%
48	49	48,5	6112	934	15.28%	611	0	0.00%	707	71	10.00%
49	50	49,5	6360	1081	17.00%	284	0	0.00%	736	74	10.00%
50	51	50,5	6525	1223	18.74%	182	28	15.50%	755	77	10.15%
51	52	51,5	6460	1324	20.49%	278	46	16.39%	748	78	10.44%
52	53	52,5	6671	1485	22.26%	189	33	17.32%	772	83	10.75%
53	54	53,5	3484	838	24.04%	184	34	18.29%	403	45	11.06%
54	55	54,5	2085	539	25.83%	169	33	19.30%	241	27	11.38%
55	56	55,5	1903	526	27.64%	166	34	20.35%	220	26	11.71%
56	57	56,5	1011	298	29.46%	107	23	21.44%	117	14	12.05%
57	58	57,5	521	163	31.30%	99	22	22.57%	60	7	12.39%
58	59	58,5	299	99	33.15%	63	15	23.74%	35	4	12.75%
59	60	59,5	254	89	35.02%	82	20	24.95%	29	4	13.11%
60	61	60,5	614	227	36.90%	175	46	26.20%	71	10	13.48%
61	62	61,5	650	252	38.80%	182	50	27.49%	75	10	13.86%
62	63	62,5	608	248	40.71%	190	55	28.82%	70	10	14.25%
63	64	63,5	431	184	42.63%	235	71	30.19%	50	7	14.65%
64	65	64,5	376	167	44.57%	160	50	31.59%	43	7	15.06%
65	66	65,5	142	66	46.52%	28	9	33.04%	16	3	15.47%
66	67	66,5	85	41	48.49%				10	2	15.90%
67	68	67,5	117	59	50.47%				14	2	16.33%
68	69	68,5	133	70	52.47%				15	3	16.78%
69	70	69,5	223	122	54.48%				26	4	17.23%
70	71	70,5	222	125	56.50%				26	5	17.70%
71	72	71,5	184	107	58.54%				21	4	18.17%
72	73	72,5	245	149	60.59%				28	5	18.66%
73	74	73,5	176	110	62.66%				20	4	19.15%
74	75	74,5	3	2	64.74%						
75	80	77,5									
Sum			**537631**	**35542**	**6,61%**	**537631**	**569**	**0.11%**	**72742**	***7328***	**10.07%**

Note. HA = highly annoyed; HSD = highly sleep disturbed.

For the number of deaths due CHD attributable to noise, the noise source-specific population attributed fraction PAF (see 3.4.5 of Guidance, Part B) calculated for Düsseldorf, was multiplied with the mortality rate for coronary heart disease and the total number of residents in Düsseldorf for females and males, separately. These products were then summed up to the total number of deaths due to coronary heart disease attributable to aircraft, road, and railway noise, respectively.

The noise-specific PAF was multiplied with the hospital discharge rate and the population number in Düsseldorf to get the number of persons with a CHD per year attributable to noise. Again, this was done separately for females and males and then summed up to the total number of persons with a CHD per year attributable to noise. Table 4.4 presents the estimated number of persons with a CHD per year and the number of deaths due to CHD, both attributable to noise in Düsseldorf.

Table 4.6: Estimated number of people suffering from CHD attributable to transportation noise in Düsseldorf

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
		RR per 10 dB L_{den}	**PAF**	**Hospital discharge / mortality rate Germany (per 100000)**		**Number residents in area**			**Total estimated hospital discharges in Düsseldorf region**			**Total estimated hospital discharges / death in Düsseldorf attributable to noise**		
		Starting value: 53 dB		Sources: European Hospital Morbidity Database WHO (2012), WHO Mortality database (2015)		Source: Amt für Statistik und Wahlen Düsseldorf (2017)			E/100000 x G	F/100000 x H	J+K	D x J	D x K	M+N
Health end point	**Noise source**			Ma	Fe	Ma	Fe	Sum	Ma	Fe	Sum	Ma	Fe	**Sum**
CHD *incidence*	Road	1,04	0,0146	1252	577	308952	326752	635704	3867	1884	5751	56	28	**84**
	Rail	1,04	0,0087	1252	577	308952	326752	635704	3867	1884	5751	33	16	**50**
	Air	1,04	0,0005	1252	577	308952	326752	635704	3867	1884	5751	2	1	**3**
CHD *mortality*	Road	1,05	0,0182	2738	2263	308952	326752	635704	8460	7395	15855	154	135	**289**
	Rail	1,05	0,0108	2738	2263	308952	326752	635704	8460	7395	15855	91	80	**171**
	Air	1,05	0,0006	2738	2263	308952	326752	635704	8460	7395	15855	5	5	**10**

Note. CHD = coronary heart diseases; RR = relative risk; PAF = average population attributive fraction; Ma = male; Fe = female. Estimated hospital discharges as an indicator for the incidence of IHD, estimated deaths due to CHD

In theory the identified NafPs with regard to noise annoyance, sleep disturbance, CHD (incidence, mortality) and children's reading impairment due to aircraft noise can be used to compare different subgroups of citizens of Düsseldorf, different districts, or different noise scenarios. In addition, the relative numbers (%HA, %HSD, % impaired) can be used to compare the health impact of noise in Düsseldorf with results from other cities or with generalised exposure-response curves as they are presented in 3.4 of this guidance document .

4.6 Estimation of DALYs due to transportation noise (HIA method 2)

Step 5

For the estimation of the status quo of the DALYs due to transportation noise we used the equations described in section 3.7 to assess the number of Disability-Adjusted Life Years attributable to transportation noise in Düsseldorf. This was done for each transportation noise source for coronary heart diseases, following the insights and methods of the GBD-project. For comparison reasons, we also show what happens when high annoyance and high sleep disturbance was included in the DALY-calculation. For children's reading impairment due to aircraft noise there is no recommendation yet for DALY calculation (see Chapters 3.4.3 and 3.5.3), because the methods are not developed well enough yet to do so in a useful way.

For coronary heart diseases (CHD), first the PAF (population attributable fraction) was calculated (Table 4.7, column D), for both incidence and mortality according to the equations described in chapters 3.5.4 and 3.7.

Subsequently, the total number of Years Lived with Disease (YLD) due to CHD disease in Düsseldorf (Table 4.7, column F) was estimated by multiplying the YLD rate per 100,000 inhabitants for coronary heart disease in Germany, obtained from the WHO database for disease burden estimates, with the number of adults exposed per 100,000 inhabitants in Düsseldorf. The underlying assumption was that the YLD rate of coronary heart disease in Germany is valid for the City of Düsseldorf. For each noise source the average YLD due to coronary heart disease attributable to noise in Düsseldorf was given by the product the number of YLDs due to coronary heart disease in Düsseldorf and the PAF (for the incidence of CHD attributable to noise).

The total number of Years of Life Lost (YLL) due to CHD in Düsseldorf (Table 4.7, column G) was estimated by multiplying the YLL rate per 100,000 inhabitants due to CHD in Germany, obtained from the WHO database for disease burden estimates, with the number of adults per 100,000 inhabitants in Düsseldorf. Again, the underlying assumption was that the YLL rate due to CHD for Germany is valid for the City of Düsseldorf. For each noise source the average YLL due to CHD attributable to noise in Düsseldorf was given by the product of the number of YLL due to CHD in Düsseldorf and the PAF (for mortality due to CHD).

Subsequently, the number of DALYs due to CHD attributable to noise in Dusseldorf was estimated by summing up the estimated number of YLDs due to CHD attributable to noise in Dusseldorf with estimated number of YLLs due to CHD attributable to noise in Dusseldorf (DALY I).

However, we also want to show what happens, when one decides to add annoyance and sleep disturbance to the DALY calculation. For high annoyance the total number of highly annoyed people per noise source was taken (Table 4.7, column C), which is also assessed earlier (see Table 4.3 to Table 4.5). A disability weight of DW = 0.01 was applied for high annoyance according to the recommendation given in Chapter

3.8.2. The duration is equal to one year. The total number of Years Lost due to disability due to high annoyance (YLD) was estimated per noise source by multiplying the absolute number of highly annoyed people (Table 4.7, column C) with DW = 0.01 (Table 4.7, column E). Since nobody is assumed to die due to annoyance, the number of Years of Life Lost due to premature mortality is 0.

Similar, for high sleep disturbance the total number of highly sleep disturbed people per noise source was taken that was already calculated (Table 4.5, column C). A disability weight of DW = 0.0175 was applied for high sleep disturbance according to the recommendation given in Chapter 3.8.2. The duration was equal to 1 year. The total number of years lost due to disability due to high sleep disturbance (YLD) was estimated per noise source by multiplying the absolute number of highly sleep disturbed people (Table 4.5, column C) with DW = 0.0175 (Table 4.5, column E). Similar to high noise annoyance, nobody is assumed to die due to sleep disturbance. Consequently, the number of Years of Life Lost due to premature mortality is 0.

Subsequently, the alternative number of DALYs attributable to noise in Dusseldorf (DALY II) was estimated by summing up the estimated number of YLDs due to CHD attributable to noise in Dusseldorf with the estimated number of YLLs due to CHD attributable to noise in Dusseldorf, and the estimated number of Years lived with disability due to high annoyance and high sleep disturbance.
The result is presented in table 4.7.

Table 4.7: DALYs for the current noise emission in Düsseldorf

A	B	C	D	E	F	G	H
Health endpoint	**Noise source**	**Average estimated prevalence (absolute numbers)**	**PAF**	**Disability Weight**	**Total number of YLD in Düssel-dorf**	**Total number of YLL in Düssel-dorf**	**Average DALYs due to noise**
High Annoyance	Road	63558		0,01	636		636 [+]
	Rail	47089		0,01	471		471 [+]
	Air	35542		0,01	355		355 [+]
High Sleep Disturbance	Road	12344		0,0175	284	0 0	284 [+]
	Rail	16551		0,0175	381	0	381 [+]
	Air	569		0,0175	13	0	13 [+]
CHD Incidence	Road		0,0146		982		14 *
	Rail		0,0087		982		9 *
	Air		0,0005		982		1 *
CHD mortality	Road		0,0182			20148	367 [#]
	Rail		0,0108			20148	218 [#]
	Air		0,0006			20148	13 [#]
DALY I							**621**
DALY II							**2760**

Note. DALY = Disability-Adjusted Life Years, CHD = coronary heart diseases, PAF = average population attributive fraction, YLD= Years of life lost due to disability, YLL= Years of Life lost due to premature death. DALY I = DALYs calculation excludes DALYs due to noise annoyance and sleep disturbance, following GBD. DALY II = DALYs calculation includes DALYs due to noise annoyance and sleep disturbance.

The number of DALYs due to noise presented in table 4.7 do have no meaning, unless compared with for example the estimated number with DALYs from other risk factors. As part of the disease burden, the GBD study has estimated the number of DALYS attributable to air pollution (including ambient particulate matter, ozone, and household air pollution), radon and lead for Germany. Applying these results on Düsseldorf (assuming that the exposure distribution in Germany is equal with Dusseldorf), this would mean that the number of DALYs due to air pollution in Dusseldorf is about 4,500; for radon 297 DALYs were estimated and for lead 202 DALYs. If the GBD-projections are true, this would mean that the disease burden caused by noise is comparable with the disease burden caused by radon and lead. The DALYs that include also annoyance and sleep disturbance cannot be compared with the DALYs for air pollution produced by the GBD, because in the GBD they are not included.

4.7 HIA assessment of the impact of noise abatement actions in Düsseldorf-Bilk on health (step 4 and step 5)

For the estimation for policy question 2 (evaluation of action plans) the HIA assessment of the impact of noise abatement actions was carried out for the following interventions:

1. Road traffic noise: Noise reducing road surfaces and speed limit 30 km/h (as compared to 50 km/h)
2. Tramway noise: Green tech rail profiles

Figure 4.7 delineates the procedures within the observation area, which shows broadly the district Düsseldorf-Bilk, located in the city centre. It includes three social environments (compare Amt für Statistik und Wahlen Düsseldorf, 2017), which comprises 94,5 hectares and inhabits 13,027 people. For the HIA assessments carried out for the district Düsseldorf-Bilk for the different noise scenarios before and after the simulated imposement of noise abatement actions we followed the same procedure as described in sections 4.4.3 and 4.6.

The HIA assessments for the tramway noise measure (green tech rail profile) rely on ERFs for railway noise, the HIA assessments for the other actions (new road surface, speed limit) rely on ERFs for road traffic noise.

For simplification, we assumed for all further calculations done for Düsseldorf Bilk the same sociographic premise as for the whole city of Düsseldorf, which seems to be reasonable (see Amt für Statistik und Wahlen Düsseldorf, 2017).

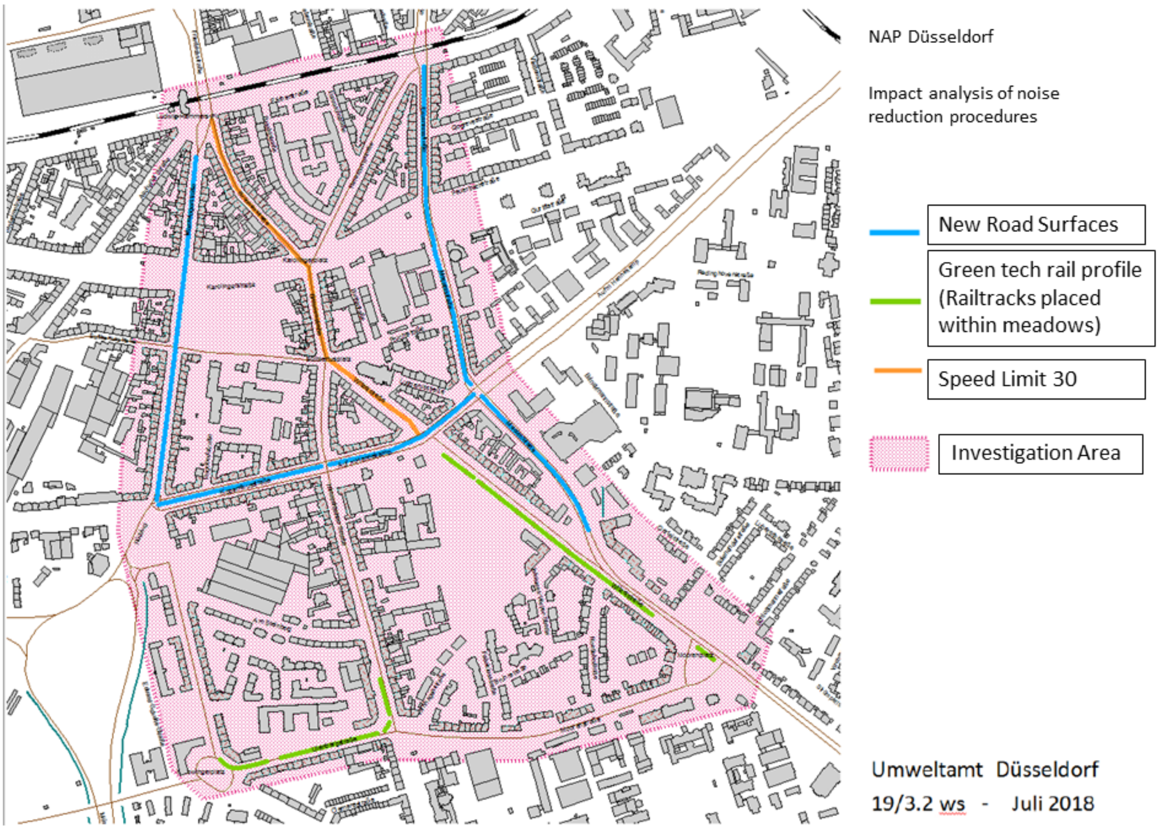

Figure 4.7: Investigation area and delineation of the three noise reduction procedures

The health impact of the two interventions to reduce road traffic noise (new road surfaces and speed limit of 30 km/h) and the intervention to reduce tramway noise (green tech rail profiles) is shown in table 4.9.

The impact of air traffic noise was not considered as aircraft noise exposure was not affected by the procedures.

Table 4.8: Theoretical display of number of affected people (HIA method 1) and DALYs (HIA method 2) before and after the imposition of a noise reducing road surface Disability weights as distributed in Table 1 still apply.

Health end Point	**Noise source**	**Average number of affected people before the new road surface and speed limit**	**Average number of affected people after the new road surface and speed limit**	**Difference in number of affected people**	**Average DALYs due to noise before the new road surface and speed limit**	**Average DALYs due to noise after the new road surface and speed limit**	**Average difference in DALYs**
		before	*after*	*(after - before)*	*Before*	*after*	*(after - before)*
		Measure: Noise reducing road surfaces and speed limit 30 km/h					
High annoyance	Road	1490(11.3%)	1385 (11.6%)	-106 (0.3%)	14.90	13.85	-1.06(7.1%)
high sleep disturbance	Road	289(2.2%)	263(2.0%)	-26(0.2%)	6.66	6.05	-0.60 (9.0%)
CHD Incidence	Road	2	2	-0	0.38	0.34	-0.04 (10.5%)
CHD mortality	Road	8	7	-1	9.76	8.81	-0.95 (9.7%)
DALY I		--	--	--	10.15	9.16	-0.99 (9.8%)
DALY II		--	--	--	31.70	29.06	-2.65 (8.4%)
		Measure: Green tech rail profiles					
High annoyance	Tram (rail)	1057 (8.1%)	992 (7.6%)	-65 (0.5%)	10.57	9.92	-0.65 (6.2%)
High sleep disturbance	Tram (rail)	395 (3.0%)	360(2.8%)	-35 (0.2%)	9.08	8.28	-0.80 (8.8%)
CHD incidence	Tram (rail)	1	1	-0	0.24	0.21	-0.02 (8.3%)
CHD mortality	Tram (rail)	5	4	0	6.05	5.50	-0.55 (9.1%)
DALY I		--	--	--	6.29	5.72	-0.57 (9.1%)
DALY II		--	--	--	25.93	23.92	-2.02 (7.8%)

Note. DALY = Disability-Adjusted Life Years, CHD = coronary heart diseases, PAF = average population attributive fraction, YLD= Years of life lost due to disability, YLL= Years of Life lost due to premature death. DALY I = DALYs calculation excludes DALYs due to noise annoyance and sleep disturbance. DALY II = DALYs calculation includes DALYs due to noise annoyance and sleep disturbance.

For the two noise abatement actions for road traffic noise, the number of DALYs excluding noise annoyance and sleep disturbance (DALY I) would decrease on average 9.8%: The number DALYs including noise annoyance and sleep disturbance (DALY II) would decrease with 8.4%.

The road traffic intervention causes a reduction of 0.3% (106 persons) in high annoyance and 0.2% in high sleep disturbance

One person less would die due to coronary heart disease.

For the noise abatement measure for tramway noise the number of DALY I hardly changes: a reduction of 0.57 DALYs was found (9.1%). The same is true for the number of estimated DALY IIs. They were estimated to decrease from 25.93 to 23.92 (7.8%).

The imposement of the green tech rail profiles causes only a reduction of 0.5 % in the number of highly annoyed and 0.2% in high sleep disturbance. No impact on CHD disease incidence or mortality is found.

Figure 4.6 already showed that the noise exposure level of most people in Dusseldorf-Bilk will not change after implementation of the proposed interventions. Consequently, the estimated health gain is low, which is accordingly demonstrated in table 4.9.

4.8 Conclusions

Analysing the two cases in Düsseldorf, has shown that different (additional) sources are needed to obtain the relevant input data for NafP (method 1) and DALYs (method 2). In particular for the DALY calculation, where in addition, not only information with regard to the severity of effects was needed, but also data on YLL and YLD. Often these data were not available at city level but at nation-wide level. The same is the case for mortality and incidence data (also needed for the estimation of the NafP). Assumptions had to be made with regard to the validity of the application of these national morbidity and mortality data to a city population. These assumptions may influence the findings of the assessment and introduce uncertainty into the assessment.
With regard to the exposure data, it was found that at least in Germany, different authorities are responsible for the noise mapping (city: road traffic noise, local railway noise; aircraft federal state authority; regional/long-distance railway: federal authority). This might lead to differences in the level of detail between noise sources concerning the number of exposed people, the boundary range of sound level classes (e.g. 1 dB-classes vs. 5 dB-classes), or the lowest starting point of sound levels considered for the noise mapping. This again might lead to differences in the accuracy of HIA between noise sources or between cities.

For both annoyance and sleep disturbance, at least in Germany, local or regional ERFs are seldom available. This is despite the fact that local/regional authorities are encouraged to carry out surveys on community responses to environmental noise parallel to noise mapping in order to obtain exposure-response functions valid on a city or noise action plan level. For these HIAs we had to apply generalized ERFs. For assessing the impact of interventions this is not a problem, since the estimated change is what you want to know. For estimating the actual number of highly annoyed or highly sleep disturbed people this can be more of a problem, since ERFs do not take into account the characteristics of the local population and/or situation.

For simplification, in the case of Düsseldorf the city-wide demographics (age, gender) were also applied to the HIA for the city district Bilk. This was mainly due to time restrictions of finalising this report; in principle, more area-related demographics would have been available for the HIA.

With regard to the HIA it was found that calculations for both NafPs and DALYs are complex and need epidemiological expertise. As has already been noted in section 2.4. DALYs are the most complex indicator and its poor overall scoring in the stakeholder constancy, which is most of all due to its impracticality and complexity in understanding, have proven to be true in these case studies. Implementing a HIA based on DALY calculation will likely be the most challenging task for everybody involved compared to the other indices.

But also the assessment of the NafP is not trivial, as for this method in particular for the estimation of the number of people suffering from physical health risks (e.g. CHD) the input of epidemiological data from different databases are needed and have to be processed in epidemiological functions not easy to be understand by non-epidemiologists. In principle, the calculation could be automated using calculation software. However this software has to be regularly updated and, again, epidemiological expertise is needed to follow changes that demand for software updates.

Irrespective of the method (DALY I or II, or NafP) some health outcomes are not sensitive to short-term changes in noise, as they take many years to develop and will not show a change for short-term change in noise exposure as evaluated in this HIA.

It is also not just the population size that hinders the assessment but also the fact that the actions taken did not result in a substantial decrease in noise exposure for most people in the area; only the higher noise levels show a significant reduction and relatively few people are exposed to these levels.

The health impact scores that turned out to be most sensitive to changes in noise exposure due to the noise interventions are the number of sleep disturbed and highly annoyed people before and after the interventions.

If it were the objective to decide between the road traffic and the tramway noise abatement actions, it would depend on the HIA method which one would be the preferred option. According to the NafPs it would depend on the context and the aims which action should be preferred. The absolute decrease in the number of affected people would speak for the road traffic interventions as it leads to the highest absolute difference in affected people, in this case due to reductions in the number of highly annoyed people. However it is questionable if one should look at the absolute numbers. If it would be the aim to protect people at night, the tramway actions would be more promising as it leads to higher reductions in the percentage highly sleep disturbed. This is also reflected by DALY II, mainly because DALY II includes a weighting of the outcomes, which gives preference to sleep disturbance compared to annoyance. While this might be reasonable, the weighting still is an arbitrary choice.

DALY I would provide little information for any preference and it is in its current form only including coronary heart disease, thus, not recommended as a method for HIA to evaluate NAPs. However, given the fact that more and more studies on the impact of noise on stroke and diabetes are being published, in near future, it should be possible to derive more robust ERFs for these effects. Consequently, these effects can be then included in DALY I.

At least, while DALY I (also in its current form) seems to work as a status quo description of the health effects of environmental noise in a larger city level, it should be supplemented by another HIA method when it comes to evaluation and comparison of noise scenarios at NAP level.

4.9 References Chapter 4

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Appendix I: Stakeholder Consultation

Delphi Environmental Health Indicator in EU Noise Guidelines (Annex III): First round

INSTRUCTION.

Annex III of the Environmental Noise Directive (END) describes a method for calculating the health impacts of exposure to environmental noise levels from different sources. Currently, Annex III is under revision, following the latest scientific evidence of the health effects of noise reviewed for an update of the formerly named Community Noise Guidelines of WHO now referred to as the Environmental Noise Guidelines for the European Region.

Existing Guidelines (such as the Good Practice Guidelines of the European Environmental Agency (EEA) provide end-users with practical and validated tools to calculate the health impacts of noise in strategic noise studies such as the Noise Action Plans (NAPs) of the Directive. It does, however, not provide guidance on how health and well-being effects can be estimated, and used to justify or establish priorities within the NAPs.

The main aim of the current project is therefore to extend noise mapping according to Article 7 of the END (Annex II) and noise action plans (Article 8) by means of a guidance tool that can be used to assess and evaluate the (cumulative) health effects at population level due to environmental noise exposure.

At the moment, several (summary) indicators are available that can be helpful for (local) authorities working in the domain of environment and health. The application of such indicators should not be a goal in itself, but should support the process and the communication between different stakeholders and to help answer the underlying questions. The choice for a particular indicator depends primarily on the question(s) that ha(s)ve to be answered (e.g. priority setting, comparison of the effects of different noise reduction measures) and the phase in the decision making process: policy preparation, decision, implementation, or evaluation of noise reducing measures.

As part of this project we ask several experts and stakeholders to share their opinion about the usefulness of different environmental health indicators. The possible range of indicators include indicators per outcome such as the number of (highly) annoyed or sleep disturbed people and indicators that summarize different health outcomes in a single number such as the disability-adjusted life years (DALYs).

The Delphi survey consists of three rounds: 1 An open inventory about the use of environmental health indicators in the European Noise Directives 2. Feedback based on the answers of the participants and statements derived from this 3. Scoring a matrix of indicators and criteria. These will take place in week between April 9 and 13.

Facilitators: Dirk Schreckenberg and Irene van Kamp

Thanks in advance for your participation!

Your background

1.	Participation in the Delphi	☐a Yes .>>>> go to question R 1_1 ☐a No
2.	Education/Discipline	
3.	What is your profession	
4.	Please indicate your level of experience with working with environmental health indicators	☐ Not at all ☐ Somewhat ☐ Neutral ☐ Considerable ☐ Very much
5.	Please indicate your level of working experience with the topic of noise, noise abatement	☐ Not at all ☐ Somewhat ☐ Neutral ☐ Considerable ☐ Very much
6.	Are you familiar with European Noise Guidelines (END)	☐ Not at all ☐ Somewhat ☐ Neutral ☐ Considerable ☐ Very much
7.	Country of Residence	

R1_1: Environmental Health Indicators

1-1.1	Please describe whether you think it is a good idea to include health indicators in the European Environmental Noise Directive (END) And hereby indicate why or why not	
1_2	What indicators do you consider as suitable for this purpose [list at maximum 5]	1 2 3 4 5
1_3	And argue for each of them why.	1 2 3 4 5
1_4	Are there any indicators you explicitly did not select	
1_5	Please argue why	
1_4	For what (type of) questions are the selected indictors suitable and for which not? (per indicator)	1 Suitable: Not suitable 2 Suitable: Not suitable 3 Suitable: Not suitable 4 Suitable: Not suitable 5 Suitable: Not suitable
1_5	What are in your view the key requirements for the indicators you selected (maximum 10) in order to be applicable as part of the END	

R1_2 Environmental Noise Health Impact Assessment

2_1	For the END, the selected health indicator can be assessed separately or the health indicators can be summarised to a total summary score of environmental noise health impacts.	1 For what (type of) questions would it be suitable to combine the health indicators to a summary score? 2 For what (type of) questions would it be suitable to assess the health indicators separately?
2_2	All in all, would you prefer separate number for each health indicators or a summary score? Why?	1 prefer strongly separate indicators 2 3 no preference/ as well as 4 5 prefer strongly summary score
2_3	Imagine you should advice to a community a procedure of assessing the health impact of environmental noise in the community as a basis for a noise action plan. Please describe in broad outline what procedure you would suggest.	

Round 2: Scoring of statements (derived from round 1) regarding the inclusion of health indicators in END

Reasons for inclusion of health indicators in END Please indicate your level of agreement with the following statements:					
	not	**A little**	**moderately**	**fairly**	**very**
The same value of LDEN does not mean the same health outcome for different sound source.					
The percentage highly noise annoyed should not be treated as a health criterion.					
The mean NafP should not be the base for noise action plans (NAP)					
The health criterion should be based on the numbers related to the health effect not on Annoyance (the number of people suffering from the noise).					
From the policy domain of air quality we know that health indicators are strong arguments for policy decisions. In assessing policy, projects, interventions et cetera health and health impacts are central, as part of Health in all policies.					
Lacking (EU-legislative) noise health indicators makes advocacy and agenda setting for health impacts due to noise exposure difficult.					
I certainly support inclusion of health indicators in the END.					
Health and noise should be better linked to each other					
Noise levels alone don't give enough information for local environmental health professionals or local policy makers to prioritize measures or identify problem areas.					
It is important to harmonize methods for strategic noise maps, so that comparison between cities/countries would be possible.					
New noise indicators should be added to END such as the number of flights and maximum noise levels.					
More knowledge about the association between specific noise characteristics (frequency, time patterns, roughness, etc) and reactions is needed.					
The core text of the END should not include health indicators. It is adequate if the dose-response relationships published according Annex III include health indicators respectively health outcomes					

	not	A little	moderately	fairly	very
Indicators are needed to describe the harmful effects (health indicators) and to correlate them to the sound exposure (acoustic indicators).					
The END should include exposure-effect-relationships.					
The END should include thresholds for the political agenda which must be set by political and societal decisions.					
Health indicators should be included in END because these indicators can trigger the necessary action, not the noise levels itself.					
The choice of indicators depends on the objective or purpose to which that indicator is to be used.					
Health Indicators in END can provide another source for environmental noise analysis at European level and potentially improve comparability among different countries, regions or cities.					
Potentially, when linking to health and submitted officially, political interest and priorities can change at citizens level, which can in turn change the administrative priorities.					
Including health in END can increased public awareness of noise.					
Decision makers want to know the size of the health effects. So they can weigh the importance against others factors.					
Room for additional remarks on this theme					

Suitable indicators Please indicate your level of agreement with the following statements:					
	not	**A little**	**moderately**	**fairly**	**very**
The average levels (Leq) for day, evening night dB, Lden					
Levels of Lnight					
The maximum noise levels at specific levels					
The number of people exposed per noise source					
The number of people exposed to certain environmental noise levels (lden, lnight etc.) per noise source					
Number of people with severe annoyance/sleep disturbance					
Probability of noise Induced awakening at night					
Percentage/number of people with other health effects: hypertension, coronary heart disease					
Disability-adjusted life years					
Health costs of noise (cost-benefit)					
The number of sensitive destinations like dwellings and schools per noise class					
The location of vulnerable subgroups					
Access to ‘quiet’ places in the neighbourhood					
The possibilities to ‘restore’					
Measurable effect of noise on sleep disturbance					
Number of people exposed to environmental noise (including all noise sources, and not only END sources)					
Relative risk for diseases due to noise					
Cardio vascular disease					
Integrated effect indexes, like e.g. ….DALYs					
Number of people experiencing reduction on exposure levels					
Speech intelligibility measured in the presence of a given sound source					
Maps of risk groups exposed to noise levels. For example, where do children live, where are schools situated, etc combined with noise levels of different sources					
Maps of noise in combination with air pollution.					
Mean distance of dwellings to "quiet" places					
Number of dwellings with and without a quiet site (a site <50 dB den/ 40 dB night)					
Proportion or number per measure of economic activity					

Room for additional remarks on this theme:					
Possible questions to address with indicators Please indicate your level of agreement with the following statements:					
	not	**A little**	**moderately**	**fairly**	**very**
Risk quantification: territorial analysis of noise exposure (per source)					
To investigate the long-term effects of noise					
How many people live above a certain level of noise					
Inventory new emerging problems					
Overall assessment of health effects of noise					
Prioritize measures, decision making, evaluation, communication with residents					
Spatial planning and temporal activities such as festivals					
For the overall evaluation of health impact.					
To answer questions like: which is the noisiest city (or country)?					
Analysis of the noise situation should be focused on the people, not on the source.					
How many people live shorter due to noise					
Agenda setting (National)					
For integration into sustainable mobility, linkages with other policy domains such as air quality.					
Choice of location for noise interventions					
Prioritizing at national or sub national scale.					
Estimation of how many people will be harmed					
Local planning process, prioritizing of measures and the net effect of noise at a certain location					
For spatial planning, linkages with other policy domains such as air quality					
Analysis of the outcomes of interventions and of noise abatement measures.					
For determining the effectiveness of the measures					
For determining the cost of measures					
Estimate the health effects of noise a national scale					
Evaluation of small scale projects and interventions					
Comparison. Single number that should be easy to understand by population.					
for violation of well-being					
How many people will be harmed					
Prioritize measures, communication with residents					
Small areas up to cities and countries					
To evaluate specific situations concerning noise and health					
A reasonable large area					
Choice of the best scenario for policy action.					

Investigate health effects in individuals or specific locations					
The environmental health indicator is not suitable for communication purposes. Therefore it's too difficult.					
Room for additional remarks on this theme:					

Key Requirements for environmental health indicators Please indicate your level of agreement with the following statements:					
	not	**A little**	**moderately**	**fairly**	**very**
It must be feasible to calculate the indicators within a certain time frame and not cost too much money.					
The indicator must be in line with indicators based on epidemiological studies that evaluated the effect of noise on health.					
To introduce as an obligatory procedure (together with the maps) a very short survey which should be performed in a chosen point in the city with the following questions: - mark on the list which sound source is the most annoying one (possible marks for more than one sound source)					
Which one (sound source) you prefer to switch off first if you have such possibility					
Perform a short intelligibility test inside the apartment					
Agreement by Member States and international community on the indicators to be used and how to interpret the numbers published.					
Guidelines for the calculation of the indicators proposed.					
Provision of confidence interval with the number reported.					
Attention to the underestimated environmental problem, especially among politicians					
The indicator should be easy to calculate					
The indicator should be easy to understand for policy makers and citizens					
Data need to be available on all scales, national to local suitable for calculating trends and comparison of different regions					
The indicator should be sensitive to small changes in noise levels (and thereby suitable to be used in comparison of spatial scenarios)					
Suitable for mapping (used in the planning process)					
The indictor should be based on evidence.					
The indicator should be based on availability of data					
The indicator should relate exposure to responses					
The indicator should be accepted					
The indicator should be understandable					

Key Requirements for environmental health indicators Please indicate your level of agreement with the following statements:					
Requirements are better noise exposure evaluation					
Requirement is good quality health data, suitable for evaluation of burden of disease.					
It must be feasible to calculate the indicators within a certain time frame and not cost too much money.					
The indicator must be in line with indicators based on epidemiological studies that evaluated the effect of noise on health.					
The indicator should be transparent,					
The indicator should be communicative.					
The indicator should be integrated with other policy domains in source and/or effect					
The indicator should include knowledge about the number of dwellings with quiet side					
The indicator should be precise					
The indicator should be practical					
The indicator should be understandable					
The indicator should provide a meaningful measure to help understand the effectiveness of actions at specific locations and a broader measure to do the same thing at regional and national level					
Room for additional remarks on this theme:					

Suitable issues for the use of one summary health indicator Please indicate your level of agreement with the following statements:					
	not	**A little**	**moderately**	**fairly**	**very**
A summary score would be useful to put the problem of noise 'on the agenda' and to assess it in combination with other environmental issues.					
The result of intelligibility test is related to the all sound sources presented in a given location					
Using DALYS would enable combined effects to be measured.					
Combined exposure scores.					
Comparison between countries, regions and cities.					
Environmental noise as one of the pollutants to be addressed by public administrations.					
General indication of the "health-status" of a determined area.					
For comparison with other negative health risk factors (such as smoking. air pollution) , i.e. in the form of DALY's; for multiple source exposure					
A summary measure of health impacts of noise is necessary information for policy makers and politicians					
The net effect of noise exposure at a certain location					
Number of people with health effects (DALY's)					
Spatial planning and interventions (quality of life focus)					
to give an "easy to understand" score for noise					
Recognizing the difference between day and night exposure.					
We must not ignore the non-cognitive adverse effects that can exist at higher exposures.					
It would be better to assess the health indicators separately if you want to compare different scenarios or measures for different sources.					
Specific analysis in a region/area with a specific problem identified. Address noise situation and health impacts focused in one (main) source. Evaluation of improvement (or worsening) of the situation could be easy.					
To see effects of measures to reduce noise					
Room for additional remarks on this theme:					

Round 3**: Linking the pre-selected indicators to the selection criteria**

In Round 3 the participants were asked to score each indicator on 8 criteria on a 5 point Likert Scale (do not agree at all - agree very much). Criteria (5a, b and c) were post-hoc summarised.
Participants were presented with an overview of the indicators (as described in Chapter 2, section x) and an explanation of the criteria (see under table).

indicator →	I Compliance with WHO guidelines	I HES Health effects screening	III CHERIO	IV Number of people affected	V DALY
Criteria ↓					
1.Relevant to quantify health effects of noise					
2.Relevant for policy use					
3.Capable to reflect changes in health effects due to changes in noise exposure					
4. Sensitive for a (frequent) change or update in method					
5a.Unbiased					
5b.Reliable					
5c.Accepted by scientific community					
6. Minimum (END) exposure data available suitable and of sufficient quality for indicator					
7. Simple to implement					
8.Understandable for the general public					
Total score					

Explanation of the criteria for the evaluation of the HIA methods

1. Relevant to quantify health effects of noise
Means that the HIA method is able to quantify the health impact of environmental noise (and not just exposure, for example).

2. Relevant for policy use
This method has a link to EU policy. That is, the method and the outcomes included fit with policy, regulations on environmental noise, with noise action plans, etc.

3. Capable to reflect changes in health effects due to changes in noise exposure
Means that the HIA method allows a change in the calculated health indicator in case of change in noise exposure.

4. Flexible and adaptable to new Erf's, severity weights and guideline values, etc.
Some methods are more sensitive to changes in limit values, weights, etc than others.

5a.Unbiased
The HIA method is unbiased with regard to the situation/conditions.

5b.Reliable
The HIA method provides the calculation of a reliable indicator meaning that repeated assessment of the indicator within the same condition would provide the same outcome. (High reliability = low random error in measurement)

5c.Accepted by scientific community
The HIA method is scientifically sound and, thus, accepted by the scientific community.

6. Minimum (END) exposure data available suitable and of sufficient quality for indicator
The minimum exposure data that is available through noise maps according to the Environmental Noise Directive (END) is suitable and of sufficient quality for indicator.

7. Simple to implement
The HIA method is simple to implement at the level of local/regional noise maps and for the evaluation of noise action plans.

8. Understandable for the general public
The general public can understand the indicator. That does not mean that the general public is able to calculate the indicator and knows or understands the formula, but that the general public understands its meaning.

RIVM

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