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European Commission
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Methodological guidance for estimating the burden of disease from environmental noise

Tomas Hellmuth
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Edited by:

Tomas Hellmuth, Thomas Classen, Rokho Kim
and Stylianos Kefhalopoulos

ABSTRACT

The World Health Organization, supported by the European Commission's Joint Research Centre, is issuing this technical document as guidance for national and local authorities in risk assessment and environmental health planning related to environmental noise. The principles of quantitative assessment of the burden of disease from environmental noise, the status of implementation of the European Noise Directive, and lessons from the project on Environmental Burden of Disease in the European countries (EBoDE) are summarized, together with a review of evidence on exposure– response relationships between noise and cardiovascular diseases. Step-by-step guidance is presented on how to calculate the burden of cardiovascular diseases and sleep disturbance. The limitations and uncertainties of estimating disability-adjusted life years and the usefulness and limitations of noise map data are discussed.

Keywords

NOISE – adverse effects
ENVIRONMENTAL HEALTH
HEALTH STATUS INDICATORS
DATA COLLECTON – methods
GUIDELINES

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Acronyms and abbreviations

CNOSSOS-EU	Common Noise aSSessment methOdS in Europe
DALY	disability-adjusted life years
CI	confidence interval
EBD	environmental burden of disease
EBoDE	environmental burden of disease in Europe
EEA	European Environmental Agency
END	Environmental Noise Directive
ENNAH	European Network on Noise and Health
EU	European Union
GBD	global burden of disease
HSD	high sleep disturbance
ICD-10	<i>International classification of diseases and related health problems, 10th revision</i>
ICBEN	International Commission on Biological Effects of Noise
IHD	ischaemic heart disease
$L_{Aeq,t,h}$	A-weighted equivalent sound pressure level over t hours
L_{den}	day-evening-night equivalent level
L_{dn}	day-night equivalent level
L_{night}	night equivalent level
MI	myocardial infarction
OR	odds ratio
PM	particulate matter
RR	relative risk
YLD	years lost due to disability
YLL	years of life lost

Acknowledgements

This project and the WHO Meeting on the Burden of Disease from Environmental Noise, held in Bonn on 14 and 15 October 2011, have been supported by funds generously provided to the World Health Organization European Centre for Environment and Health (WHO-ECEH) by the German Government through the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

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University of Bielefeld, Germany
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Foreword

Noise pollution is one of the most frequently perceived environmental health issues in Europe. One in three individuals is annoyed during the daytime and one in five suffers disturbed sleep at night because of traffic noise. Epidemiological evidence indicates that those chronically exposed to high levels of environmental noise have an increased risk of cardiovascular diseases such as myocardial infarction. Thus, noise pollution should be considered as a threat to public health in modern times.

Responding to the WHO guidelines for community noise, published in 1999, the European Parliament and Council enacted the Environmental Noise Directive (END) for the management of environmental noise in 2002. In accordance with the END, most EU countries have now produced strategic noise maps and action plans on environmental noise. In 2009, the WHO European Centre for Environment and Health (WHO-ECEH) developed Night noise guidelines for Europe for policy-makers to consider in framing legislation for surveillance and control of night noise.

At the Fifth Ministerial Conference on Environment and Health, in Parma, Italy in March 2010, the Member States urged WHO to develop suitable guidelines on environmental noise policy. With the support of the European Commission's Joint Research Centre (JRC), WHO published the Burden of disease from environmental noise in 2011 to provide assistance to policy-makers in quantifying the health impacts of environmental noise. That publication concluded that at least one million healthy years of life are lost in the urban population of the EU as a result of environmental noise, placing noise pollution as the second most burdensome environmental hazard after air pollution. The document provided a strong health-based argument to policy-makers and their advisers for stringent control of noise pollution.

Supported by the JRC, the WHO-ECEH has now prepared this detailed technical guidance to EU countries in assessing the burden of disease from environmental noise. The core is the step-by-step guide for quantitative assessment of disability-adjusted life years (DALYs). Examples are provided as to how to use the exposure data obtained from END noise maps for calculating DALYs in six European countries. The limitations of the END data and the uncertainties of DALY estimation methods are also discussed.

We are grateful to those who have contributed to the preparation of this document. The Member States of WHO Regional Office for Europe endorsed a new European health policy, Health 2020, which emphasizes the importance of primary prevention, public health and "health in all policies" in tackling the social and environmental determinants of health. The Regional Office believes that this work will help countries implement the Parma Declaration and contribute to protecting the population of Europe from the adverse health impacts of noise pollution.

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Executive summary

WHO uses a methodology to estimate the burden of disease in the population in order to inform policy-makers in public health. The most commonly used summary measure of population health is the disability-adjusted life year (DALY), a health gap measure that extends the concept of potential years of life lost due to premature death to include equivalent years of healthy life lost by virtue of individuals being in states of poor health or disability. One DALY can be thought of as one lost year of healthy life.

Urbanization, economic growth and motorized transport are the major driving forces for exposure to environmental noise and its effects on health. In order to estimate the burden of disease due to environmental noise, WHO uses a quantitative risk assessment approach in comparative risk analysis. The burden of disease from environmental noise can be estimated using the WHO environmental burden of disease (EBD) approach.

In 2002, the European Parliament and Council adopted Directive 2002/49/EC relating to the assessment and management of environmental noise, known as the Environmental Noise Directive (END). This aims to provide a basis for developing European Union (EU) measures to reduce the noise emitted by major sources, in particular road and rail vehicles and infrastructure, aircraft, outdoor and industrial equipment and mobile machinery. Based on available but incomplete reports, a limited quality analysis of the strategic noise maps and action plans has been carried out.

The results of the strategic noise mapping undertaken in accordance with the END make up a useful database for burden of disease assessment. While the first round of strategic mapping should be regarded as a pilot project and a probe for describing the exposure of the population to environmental noise, the resulting numbers of people exposed, given in single decibel bands, can still be relevant. For these data to be useful, however, account must be taken of the uncertainties and limitations involved in the strategic mapping process. This is crucial, especially in making international comparisons.

Several gaps in the coverage and representativeness of END exposure data make the data alone insufficient for nationwide health impact assessments. Moreover, many countries still lack the resources to produce complete (or indeed any) strategic noise maps. Makeshift solutions are needed to overcome these data shortages. For instance, the distribution of exposure in minor agglomerations can be roughly approximated by generalizing from representative sample populations for which data are easier to obtain. Similarly, exposure from minor roads, railways and airports can be approximated by sampling representative road/rail districts and airports (including overseas equivalents). For low-exposure data as a crude first approximation, a flat distribution can be assumed in the low-noise regime. Using conversion formulas, night-time exposures can be approximated from daytime data and datasets employed that use alternative descriptors.

The cardiovascular effects of noise have evoked growing interest in recent years. There is now sufficient evidence that noise affects cardiovascular health. High blood pressure and ischaemic heart diseases (IHD) (including myocardial infarction) show a high prevalence in industrialized countries, where they are a major cause of death. The exposure-response functions for cardiovascular endpoints are given in detail in the WHO publication *Burden of disease from environmental noise: quantification of healthy life years lost in Europe*.¹

¹ *Burden of disease from environmental noise: quantification of healthy life years lost in Europe*. Copenhagen, WHO Regional Office for Europe, 2011.

The step-by-step guidance contained in this document, defining the steps to be taken when processing comparative health risks analysis, follow the rules of good practice in the environmental burden of disease calculation, where information about substantial health outcomes, exposure levels of the population, reliable exposure-response relations and baseline health data are key prerequisites.

Step 1. Selecting health endpoints (=IHD and high sleep disturbance)

Step 2. Selecting exposure-response functions

Step 3. Aggregating exposure data from country-specific strategic noise maps (if available)

Data from the first round of END reporting, carried out in 2007, have recently been aggregated and are available through the Noise Observation and Information Service for Europe.²

Step 4. Processing of health data

Baseline health data for the selected health outcomes should be obtained as ancillary inputs for EBD modelling. For IHD, health data (especially for mortality) can preferably be obtained from national and regional health authorities and statistics, but country-specific data in the harmonized health statistics database held by WHO³ can also be used.

For high sleep disturbance, no additional health data are necessary since the percentage of people affected is directly expressed by the exposure-response functions. In disease classification, high sleep disturbance is most closely related to primary insomnia.

Step 5. Calculation of the EBD

The EBD calculation aims to express as a single number the burden of disease attributable to a given environmental stressor. This EBD is expressed in DALYs, which are calculated by summarizing years lived with disability and years of life lost due to premature death.

For calculation of DALYs, the health burden due to IHD morbidity and high sleep disturbance is represented using different disability weights, which describe the severity of these conditions.

Step 6. Communication/dissemination of the results

EBD modelling enables an easy comparison of different health outcomes caused by different environmental stressors, through the summarizing of all information into a single number (the value of the DALY metric). On the other hand, it also has some weaknesses resulting from uncertainties and other limitations arising out of study designs. Consequently, when the results of the EBD calculation are presented, there is always a strong need for adequate risk communication to address the uncertainties and limitations.

There are various uncertainties and assumptions in EBD estimates that are not often made explicit. Knowledge about environmental health impacts is incomplete and a variety of assumptions need to be made for calculating the EBD. A typology of uncertainties can be used systematically to identify

² Noise Observation and Information Service for Europe - NOISE [online database]. Copenhagen, European Environment Agency, and Malaga, European Topic Centre on Spatial Information and Analysis, 2012 (<http://noise.eionet.europa.eu/index.html>, accessed 17 March 2012).

³ Health statistics and health information systems. Disease and injury country estimates [online database]. Geneva, World Health Organization, 2009 (http://www.who.int/healthinfo/global_burden_disease/estimates_country/en/index.html, accessed 15 May 2012).

and describe uncertainties. Alertness towards uncertainties and a structured approach to the assessment and communication of uncertainties can lead to a more balanced interpretation of the results of assessments.

Environmental noise is a threat to public health, with negative effects on human health and well-being. Exposure assessments relating to the first round of noise mapping suggest that around 40 million people across the EU are exposed to noise above 50 dB from roads within agglomerations during the night, and over 25 million people are exposed to noise at the same level from major roads outside agglomerations. Common action to mitigate the effect is, therefore, urgently needed at international, national and even local level. If the aim of reducing noise is to be achieved, public health policies need to be underpinned by reliable evidence-based quantitative risk assessment methods.

This methodological guidance for estimating the burden of disease from environmental noise, which follows on from WHO's publications *Night noise guidelines for Europe*⁴ and⁵, provides technical support to Member States in developing policies for public health protection from environmental noise.

⁴ WHO Regional Office for Europe (2009). *Night noise guidelines for Europe*. Copenhagen, WHO Regional Office for Europe (http://www.euro.who.int/__data/assets/pdf_file/0017/43316/E92845.pdf, accessed 17 March 2012).

⁵ WHO Regional Office for Europe (2011). *Burden of disease from environmental noise: quantification of healthy life years lost in Europe*. Copenhagen, WHO Regional Office for Europe (http://www.euro.who.int/__data/assets/pdf_file/0008/136466/e94888.pdf, accessed 17 March 2012).

1. Introduction

Environmental noise is a threat to public health, with negative effects on human health and well-being. Environmental noise is one of the most frequently complained about environmental problems in Europe. In order to provide evidence-based support to local and national policy-makers in risk assessment and management related to environmental noise, the World Health Organization European Centre for Environment and Health (WHO-ECEH) published the *Night noise guidelines for Europe* in 2009 (1) and the Burden of disease from environmental noise - quantification of healthy life years lost in Europe (2).

In the meantime, evidence has accumulated indicating that there are more serious effects on health from environmental noise than were previously known. Cardiovascular diseases such as myocardial infarction and hypertension are consistently associated with exposure to environmental noise. In 2010, most European Union (EU) member states reported to the European Environmental Agency (EEA) and the European Commission strategic noise maps and action plans to reduce noise exposure, as required by the environmental noise directive (END) (3). The evidence base for more precise estimation of the burden of cardiovascular disease and sleep disturbance from environmental noise is available in the EU member states. In 2009, WHO-ECEH supported a project on estimating the burden of disease for selected environmental stressors (Environmental Burden of Disease in the European countries (EBoDE) project), which estimated the burden of sleep disturbance and cardiovascular diseases in six European countries. Unfortunately, data and information on the exposure level and health impacts of environmental noise are very limited in the countries of south-eastern Europe and the newly independent states. There is a strong need for knowledge transfer and capacity-building in these countries.

On 14-15 October 2010, WHO-ECEH convened a group of international experts and representatives of the European Commission's Joint Research Centre and the European Environment Agency in Bonn on the Burden of Disease from Environmental Noise for the purposes of:

- establishing a framework for applying the method used in the EBoDE study to as many European countries as possible in order to estimate the burden of disease from environmental noise; and
- identifying the needs of the newly independent states and south-eastern European countries for capacity-building in the area of health risk assessment of environmental noise.

The conclusions and recommendations of the Meeting associated with the first point are presented in this booklet as a WHO technical document to serve as guidance for national and local authorities and experts involved in the risk assessment of, and environmental health planning for, environmental noise.

The problems associated with the second point are presented in a separate publication on *Needs assessment of capacity-building on health risk assessment of environmental noise: case studies*, also published in 2012 (4).

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2. Methods of estimating the environmental burden of disease

Sophie Bonjour,⁶ Annette Prüss-Üstün⁶

Introduction

WHO has developed a methodology to evaluate the global burden of disease (GBD) and to quantify the state of a population's health in order to determine strategic planning and set priorities for action in public health. Summary measures of population health have, therefore, been developed that combine information on mortality and non-fatal health outcomes. These summary measures can be divided into two distinct categories: health expectancies and health gap measures (1).

The most common measure is disability-adjusted life years (DALYs), a health gap measure that extends the concept of potential years of life lost due to premature death to include equivalent years of healthy life lost by virtue of individuals being in poor health or suffering disability. One DALY can be thought of as one lost year of healthy life and the burden of disease as a measure of the gap between current health status and an ideal situation where everyone lives into old age, free of disease and disability (2).

Evidence-based methods to evaluate the environmental burden of disease

Between 2002 and 2009, WHO published the impacts on health attributable to 26 major preventable risk factors for health, such as childhood and maternal underweight, unsafe sex, tobacco and alcohol abuse, environmental and occupational risk factors, etc., by WHO region in a comparative and internally consistent way (3–5). To assist countries develop their own estimates, WHO has coordinated the preparation of practical guidance in the form of a series of guides for estimating the disease burden at national or local levels for the following selected environmental and occupational risk factors (6):

indoor smoke from solid fuel use	lead
outdoor air pollution	mercury
water, sanitation and hygiene	occupational carcinogen, dust, noise
solar ultraviolet radiation	malnutrition
climate change	second-hand smoke.

The method used to calculate the environmental burden of disease (EBD) is based on an exposure approach, supported by a comprehensive analysis of the evidence for the given health risks. Exposure-response relationships for a given risk factor are obtained from epidemiological studies and the derived attributable fractions are then applied to the disease burden, expressed in deaths or DALYs, associated with the risk factor.

⁶ Department of Public Health and Environment, WHO headquarters.

Expert opinion method to quantify the EBD

In 2006, WHO published a report entitled *Preventing disease through healthy environments: towards an estimate of the global burden of disease (7)*, estimating how much global disease could be prevented by modifying the environment (Box 1).⁷ This work builds on previous efforts undertaken by WHO to estimate the GBD caused by 26 risk factors, published in the *World health report 2002 (3)*, and involves a systematic review of literature as well as surveys of over 100 experts worldwide. The report gives, for 85 out of the 102 major diseases and injuries classified by WHO, the preventable fraction of disease that can be attributed to the environment. These environmental contributions are sometimes available by region, by economic status (high/low income countries), by age group or by gender, depending on the available data and the domain of expertise of the experts.

Box 1. Definition of the modifiable environment

- Air, soil and water pollution by chemicals or biological agents
- Ultraviolet and ionizing radiation
- Built environment
- Noise, electromagnetic fields
- Occupational risks
- Agricultural methods, irrigation schemes
- Anthropogenic climate changes, degradation of ecosystems
- Individual behaviour related to the environment, such as hand-washing, food contamination with unsafe water or dirty hands

Source: Prüss-Üstün & Corvalán (7).

In 2007, WHO released the first ever country-by-country analysis of the impact environmental factors has on health for its 192 Member States (8).⁸ This analysis has recently been updated to reflect the newly published WHO country health statistics (9).

Remarks on the uncertainty of the methods

A number of potential sources of error may arise in estimating the EBD. These can come from: (i) the measure of exposure, (ii) the exposure-risk relationship, (iii) the assumptions made in the applicability of the exposure or exposure-risk relationship to the country of concern, (iv) health statistics, and (v) expert opinions (if used). While it is generally not possible to estimate a formal confidence interval (CI) (given that the uncertainty of the various data sets is not always known), it is possible to estimate a range of possible values the environmental disease burden may take (a sort of sensitivity analysis), based on different input parameters and assumptions. Such an analysis is not provided in the preliminary country profiles of the EBD, but should be performed in the national process of reviewing these profiles. Elements for performing such a sensitivity analysis are provided in the guides documenting the methods for estimating the disease burden (4,6).

⁷The following are excluded from the definition: individual choices, such as alcohol and tobacco consumption, drug abuse, diet; natural environments that cannot reasonably be modified (rivers, etc.); unemployment (provided that it is not linked to the degradation of the environment); natural biological agents (such as pollen); and person-to-person transmission that cannot reasonably be prevented by environmental interventions.

⁸ WHO counts 193 Member States since 2006, but the latest country health data available are from 2004, when only 192 countries were Members.

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3. Process, results and lessons of the EBoDE project

*Otto Hänninen*⁹

Introduction

The health impacts of environmental stressors range from mild psychological effects (such as annoyance from noise), to effects on morbidity (such as asthma or cardiovascular disease caused by exposure to air pollution) to increased mortality (for example, lung cancer provoked by radon exposure). As these examples show, the health effects of environmental factors vary considerably with regard to their severity and duration. This makes it difficult to compare different (environmental) health effects and to set priorities in health policies and research programmes.

Efficient public health policies should allocate resources for maximum benefit to health while avoiding undue interference with other societal functions and human activities. Comparison and prioritization of environmental health effects are key to information-based policy development and allow for:

- comparative evaluation of environmental health impacts (“how bad is it?”)
- evaluation of the potential of environmental policies (greatest reduction of disease burden)
- communication of health risks.

Objectives

The EBoDE project was set up in order to update the previous assessments, to add stressors relevant to the European Region, to provide harmonized EBD assessments for participating countries, and to develop and make available the methodology and databases for other countries (1). The specific objectives are to provide:

- harmonized EBD estimates for selected environmental stressors in six countries;
- comparability of the quantifications and ranking of the EBD
 - between countries
 - within countries
 - between environmental stressors;
- qualitative assessments of variation and uncertainty in the input parameters and results.

Methods

EBD associated with nine stressors (benzene, dioxins, second-hand smoke, formaldehyde, lead, traffic noise, ozone, particulate matter (PM) and radon) was estimated in six participating countries (Belgium, Finland, France, Germany, Italy and the Netherlands). Exposure data were estimated from international or national (benzene, dioxins, formaldehyde, lead) data sources.

Three estimation methods were used, depending on the availability of exposure-response functions for the selected endpoints. The optimal method is based on epidemiological evidence and attributable fraction of burden of disease. In the absence of epidemiological evidence,

⁹ National Institute for Health and Welfare, Kuopio, Finland.

toxicological unit risk models were used for benzene, dioxins, lead, sleep disturbance from noise, and the morbidity outcomes for PM. In some cases additional distributional modelling was applied to process a threshold (lead, formaldehyde) and to reach a diagnosed health state (lead). The methods are described in more detail in the EBoDE final report (2). The background burden of disease was estimated from WHO data.

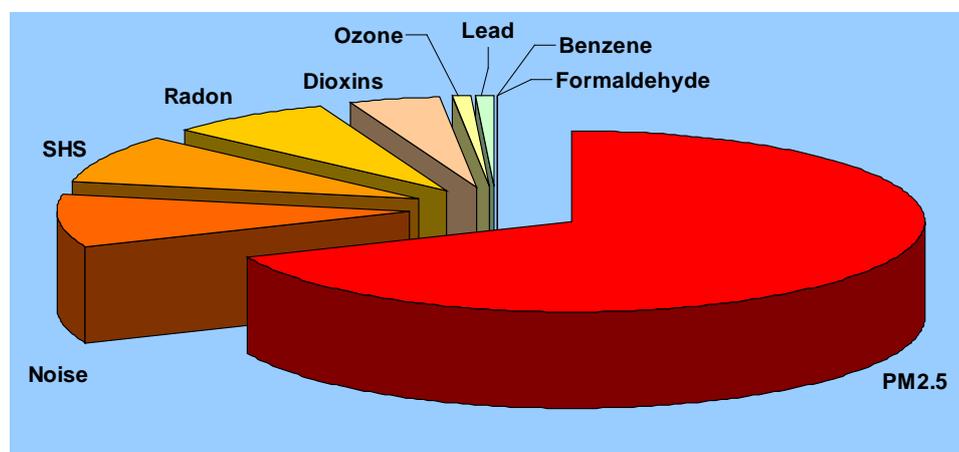
Results were calculated as standard discounted (3%) and age-weighted estimates with lag and without discounting or weighing.

Results

The results suggest that 3-7% of the discounted and age-weighted burden of disease in the participating countries may be associated with environmental stressors. Of the participating countries, Finland had relatively the heaviest burden of disease and the lightest EBD, while for Italy this was vice versa.

PM is estimated to be the leading factor associated with 6 000-10 000 DALYs per million people, followed by noise, second-hand smoke and radon (with overlapping estimate ranges from 600 to 1 500 DALY per million) (Fig. 1).

Fig. 1. Relative contribution of the nine targeted stressors to the burden of disease (undiscounted, non-age-weighted DALYs) attributed to these stressors, average over the six participating countries



Source: WHO Regional Office for Europe (3).

Discussion

Some of the EBD estimates contain substantial uncertainties that could be only partly quantified. However, quantification of selected uncertainties and comparison of the results with independent earlier assessments indicate that the overall range of the estimates from 2 to 10 000 DALYs per million annually is relatively robust. Some of the stressor estimates are overlapping, in which case their ranking is highly uncertain; this applies especially to the three runner-up stressors: noise, second-hand smoke and radon. Estimates for dioxins contain the largest uncertainties (Fig. 2).

Fig. 2. Relative public health impact (in undiscounted, un-age-weighted DALYs) of the selected environmental stressors in the participating countries^a

Non-discounted values

		Certainty of the assessment		
		High	Medium	Low
Public health impact	High	Particulate air pollution (6000-10 000)		
	Medium	Second hand smoke (800-1200) Radon (600-900)	Traffic noise (500-1100) Lead (100-500)* Ozone (40-200)	Dioxins (<500)
	Low	Benzene (2-4)		Formaldehyde (0-2)*

Numerical values indicate non-discounted DALYs per million people in the six participating countries.
* a numerical model has been used to estimate threshold exceedances.

^a Numerical ranges reflect quantitative uncertainty in the average estimate.

Source: EBoDE (1).

Environmental health policies should in particular target effectively the four highest impact exposures: PM, noise, second-hand smoke and radon.

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4. State of implementation of the Environmental Noise Directive

*Balazs Gergely*¹⁰

Introduction

Following a proposal by the European Commission in 2000, the European Parliament and Council adopted Directive 2002/49/EC of 25 June 2002 relating to the assessment and management of environmental noise (the END) (1).

The END aims to “define a common approach intended to avoid, prevent or reduce on a prioritized basis the harmful effects, including annoyance, due to the exposure to environmental noise”. It aims to provide a basis for developing (separate) EU measures to reduce noise emitted by major sources, in particular road and rail vehicles and infrastructure, aircraft, outdoor and industrial equipment and mobile machinery.

In pursuit of those aims, the END focuses on three action areas that should be progressively implemented, namely action to enable:

- the determination of exposure to environmental noise through noise-mapping based on common assessment methods;
- the adoption of action plans by the member states based upon the results of noise-mapping;
- public access to information on environmental noise and its effects (2).

Periodic reporting is required with prescribed data flows applying from certain dates onwards and evolving towards five-year cycles incorporating regular reviews. An overview of the main data flows is provided in Table 1. The first (and current) implementation cycle is characterized by the need to establish and report the policy infrastructure against the background of previously existing (or lacking) provisions in the member states that often diverged widely.

Status of implementation of the END

To date, all member states have transposed the END into national law and no major gaps have been identified. All member states have designated competent authorities and administrative bodies for the purpose of implementing END. Most countries reported existing control programmes and limit values as well as the mandatory list of major roads, railways, airports and agglomerations.

Many data were, however, reported late, thereby hampering the necessary compliance checks. Several reports on strategic noise maps due on 30 December 2007 arrived more than a year late, while many reports delivered on time were updated after the reporting deadline. This has led to difficulties and delays in analysing the reports, many of which continue to be under review. Although the deadline was mid-July 2009, only 19 member states had submitted summaries of their noise action plans by that date.

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Table 1. Data-flows resulting from the reporting obligations under the END

Data flow	Summary description of information to be reported to the European Commission	Legally binding deadline	Updates by MS	END provision
DF1	Major roads, major railways, major airports and agglomerations (for first round of noise mapping in 2007 and action plans in 2008): <ul style="list-style-type: none"> • agglomerations $\geq 250\,000$ inhabitants • major civil airports $\geq 50\,000$ movements/year • major roads ≥ 6 million vehicles/year • major railways $\geq 60\,000$ trains/year 	30 June 2005	Mandatory every 5 years	Art. 7-1
DF2	Competent bodies for strategic noise maps, action plans and data collection	18 July 2005	Any time	Art. 4-2
DF3	Noise limit values in force or planned and associated information	18 July 2005	Possible at any time	Art. 5-4
DF4	Strategic noise maps pursuant to Annex VI (first round) for: <ul style="list-style-type: none"> • agglomerations $\geq 250\,000$ inhabitants • major civil airports $\geq 50\,000$ movements/year • major roads ≥ 6 million vehicles/year • major railways $\geq 60\,000$ trains/year 	30 December 2007	Mandatory every 5 years	Art. 10-2 Annex VI
DF5	List of major roads, major railways, major airports and agglomerations designated by countries (for second round of noise mapping due in 2012): <ul style="list-style-type: none"> • agglomerations $\geq 100\,000$ inhabitants • major civil airports $\geq 50\,000$ movements/year • major roads ≥ 3 million vehicles/year • major railways $\geq 30\,000$ trains/year 	31 December 2008	Possible at any time	Art. 7-2
DF6	Noise control programmes carried out and noise measures in place for: <ul style="list-style-type: none"> • agglomerations $\geq 250\,000$ inhabitants • major civil airports $\geq 50\,000$ movements/year • major roads ≥ 6 million vehicles/year • major railways $\geq 60\,000$ trains/year 	18 January 2009	No update	Art. 10-2 Annex VI 1.3 & 2.3
DF7	Action plans pursuant to Annex VI (and any criteria used in drawing up action plans) for: <ul style="list-style-type: none"> • agglomerations $\geq 250\,000$ inhabitants • major civil airports $\geq 50\,000$ movements/year • major roads ≥ 6 million vehicles/year • major railways $\geq 60\,000$ trains/year 	18 January 2009	Mandatory every 5 years	Art. 10-2 Annex VI + Art. 8-3
DF8	Strategic noise maps related data pursuant to Annex VI (second round) for: <ul style="list-style-type: none"> • agglomerations $\geq 100\,000$ inhabitants • major roads ≥ 3 million vehicles/year • major railways $\geq 30\,000$ trains/year • major civil airports $\geq 50\,000$ movements/year 	30 December 2012	Mandatory every 5 years	Art. 10-2 Annex VI
DF9	Noise control programmes enacted prior to the entry into force of the END for: <ul style="list-style-type: none"> • agglomerations $\geq 100\,000$ and $< 250\,000$ inhabitants • major roads ≥ 3 million and < 6 million vehicles/year • major railways $\geq 30\,000$ and $< 60\,000$ trains/year • major civil airports $\geq 50\,000$ movements/year 	18 January 2014	No update	Art. 10-2 Annex VI 1.3 & 2.3
DF10	Action plans pursuant to Annex VI (and other criteria used in drawing up action plans) for: <ul style="list-style-type: none"> • agglomerations $\geq 100\,000$ and $< 250\,000$ inhabitants • major roads ≥ 3 million and < 6 million vehicles/year • major railways $\geq 30\,000$ and $< 60\,000$ trains/year • major civil airports $\geq 50\,000$ movements/year 	18 January 2014	Mandatory every 5 years	Art. 10-2 Annex VI + Art. 8-3

To date, the Commission has completed a review of existing measures related to sources of environmental noise (3).

In addition to completing the assessments of the noise maps and action plans, the Commission's efforts (supported by the Joint Research Centre) have focused on developing harmonized methods (CNOSSOS-EU) for assessing exposure to noise and consequent harmful effects according to Article 6.2 of the END (4).

While some member states have expressed concern about the potential cost implications associated with the proposed new methods, the Commission expects such impacts to be minor because these methods would generally reflect the latest practices already applied at national level, with only slight modifications.

Review of the END

While the Commission keeps the implementation of the END under review, the completion and publication of a formal report has been postponed to align with the above-mentioned overall delays in implementation.

A report for the European Parliament and the Council on the implementation of the END focusing on urban areas was adopted by the Commission in 2011 (5).

The Milieu/TNO/RPA consultancy has been contracted to study the state of implementation of the END, including obstacles to implementation and possible options for its revision, including problems associated with such a revision. A questionnaire consultation made by Milieu shows that member states are willing to accept modifications of the current legislation, mainly to provisions that are unclear, to the computation methods and to the way of reporting. Various stakeholders also expressed their views on the problems of the current legislation experienced during implementation.

WHO's *Night noise guidelines for Europe* (6) present new evidence of the health damage of night-time exposure to noise and recommend threshold values that, if breached at night, would threaten health. These include an annual average night-time exposure to noise not exceeding 40 decibel (dB) outdoors.

Conclusion

Based on the available but incomplete reports, a limited quality analysis of the strategic noise maps and action plans was carried out with assistance from the EEA and the European Topic Centre in February 2012. This assessment relating to the first round of noise mapping suggests that around 40 million people across the EU are exposed to noise levels above 50 dB from roads within agglomerations during the night. More than 25 million people are exposed to the same level of noise from major roads outside agglomerations. These numbers are expected to be revised upwards as more noise maps are received and/or assessed. The ongoing assessment has also shown, however, that it remains difficult to present robust figures on the number of people being exposed to excessive noise levels. Difficulties relate, inter alia, to the fact that exposure data for roads, rail, airports and agglomerations cannot easily be added without the risk of double counting. Analysis has furthermore shown that the various assessment methods applied to date in member states are not equivalent and lead to differing results that cannot be compared.

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5. Exposure– response relationship for cardiovascular diseases

Wolfgang Babisch¹¹

Introduction

Urban noise causes a lot of concern in the population. It causes annoyance, disturbs sleep, affects the cognitive function in schoolchildren, causes physiological stress reactions and can cause cardiovascular problems in chronically noise-exposed subjects (1,2). In particular, adverse effects occur when noise interferes with communication, concentration and sleep. Short-term changes in circulation, including blood pressure, heart rate, electrocardiogram, cardiac output and vasoconstriction as well as the release of stress hormones, including the catecholamines adrenaline and nor-adrenaline and cortisol, have been studied in experimental settings in animals and humans (3,4). Classical biological risk factors, including blood pressure, blood lipids and blood clotting factors have been shown to be elevated in subjects exposed to high levels of noise. Such vegetative changes also occur during sleep without any conscious control. Noise affects the autonomous nervous system and the endocrine system either directly or indirectly, which in turn affects the metabolic homeostasis (physiological balance) of the organism, including biological risk factors, thus increasing the risk for manifest disorders in the long term (5). Directly, in this respect, means that the activation of the regulatory system is determined by direct interaction of the acoustic nerve with other parts of the central nervous system. This is particularly relevant during sleep, where autonomous responses to single noise events, including changes in blood pressure and heart rate, have been shown in subjects whose sleep was not consciously disturbed by noise. Indirectly means that the subjective perception of sound, its cognitive interpretation and the available coping abilities play a role in physiological reaction. Repeated temporal changes in biological responses can result in persistent metabolic dysfunction of the organism, which promote the development of chronic disorders such as atherosclerosis, hypertension and ischaemic heart diseases in the long run in subjects chronically exposed to noise. The general stress theory is the rationale behind these reactions.

The cardiovascular effects of noise have evoked growing interest in the recent years. This is both because evidence has accumulated showing that noise affects cardiovascular health, and because high blood pressure and ischaemic heart diseases (including myocardial infarction) are highly prevalent in industrialized countries and a major cause of death. According to the WHO global burden of disease study (6), IHD is the leading cause of death in developed and developing countries (22.8% and 9.4% of total deaths, respectively).

Meta-analyses

Systematic and classical reviews were carried out during recent years regarding the impact of community noise on cardiovascular health (7,8). These were the basis for expert groups in WHO's normative work on guidelines for the assessment of cardiovascular morbidity due to environmental noise (9). Road traffic noise has been shown to increase the risk of IHD, including myocardial infarction (MI). There is evidence that both road traffic noise and aircraft noise

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increase the risk of high blood pressure (hypertension). Very few studies exist regarding the cardiovascular effects of other environmental noise sources, such as rail traffic.

Road traffic noise

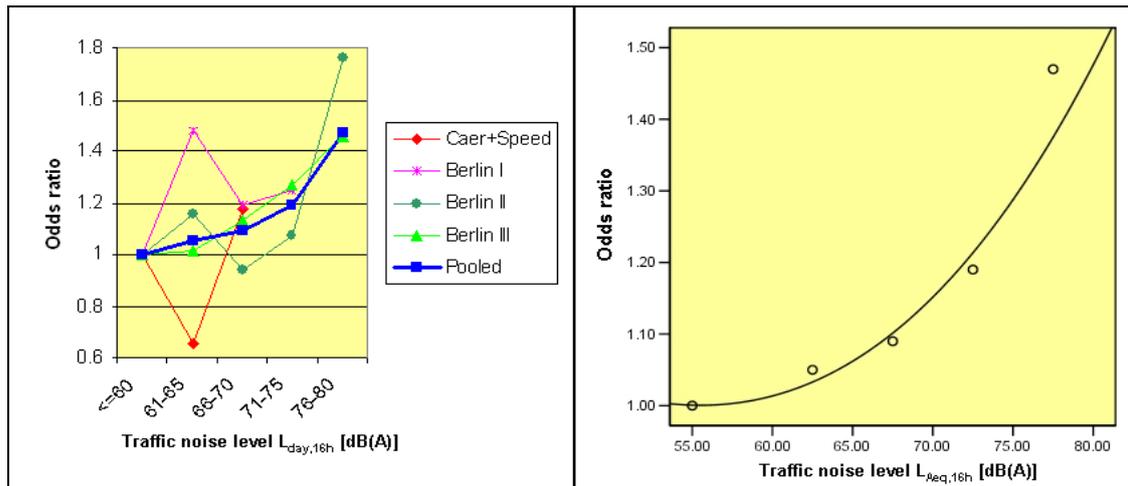
With respect to the association between road traffic noise and hypertension, the picture was not clear at the beginning of this decade. No common exposure-response curve has been developed for this association so far. More recent methodologically well designed studies, however, have revealed consistent results pointing to an increased cardiovascular risk among subjects that live on noisy streets (10–12). These cross-sectional studies showed significant odds risks (OR) for high blood pressure in the range between 1.05 (95% CI: 1.00-1.10) per 5 dB increase in the noise level ($L_{Aeq,24h}$, range: 45-75 dB) and 1.38 (1.06-1.80) per 5 dB increase in the noise level ($L_{Aeq,24h}$ range \approx 40 -70 dB) (11,12). A new meta-analysis has been published estimating an OR of 1.034 (95% CI: 1.011–1.056) per 5 dB increase in the noise level ($L_{Aeq,16h}$ range \approx 45–75 dB) (13). Air pollution was generally not considered as a potentially confounding factor in noise studies on cardiovascular outcomes, and noise was not considered in air pollution studies. In two Dutch cross-sectional study samples looking at the combined effects of road traffic noise and air pollution on the prevalence of hypertension, the odds ratios for noise did not wane after adjustment for air pollution, particularly, in the group of subjects aged 45-55 years (14). Adjusted OR of 1.09 (1.01-1.18) and 1.18 (1.04-1.33), respectively, per 5 dB increase in the noise level (L_{den}) were found in this age group. One study was able to distinguish between the exposure of the living room during the day and the bedroom during the night, suggesting that the increased risk of hypertension was more strongly related to the exposure during the night and related sleep disturbances (15).

The picture regarding IHD as an outcome was clearer (7). The subjects chosen for study were mainly men with respect to the statistical power of the study design because cardiovascular diseases are more frequent in middle-aged male subjects. There is, however, not much reason to believe from a biological point of view why the relative effects of noise stress should be different between the sexes, particularly if potentially modifying factors are taken into account (for example, patterns of activity, menopausal/hormonal state, frequency of visiting a doctor). In the case-control studies carried out in Berlin, no detailed noise data were available for streets with noise levels ($L_{Aeq,16h}$) below 60 dB (16,17). For higher road noise categories, however, increases in risk were consistently found. The cohort studies carried out in Caerphilly and Speedwell, on the other hand, did not give much of an indication of an increased risk of IHD for subjects who lived in areas where the daytime average sound pressure level ($L_{Aeq,16h}$) was less than 60 dB (18). Based on these five studies, a pooled exposure-response curve was derived for the relationship between the road traffic noise level during daytime outdoors at the most exposed façade and the incidence of myocardial infarction (19) (Fig. 3). The curve suggests an increase in risk for noise levels outdoors above 60 dB during the daytime (polynomial fit: $OR = 1.63 - 6.13 \times 10^{-4} \times L_{Aeq,16h}^2 + 7.36 \times 10^{-6} \times L_{Aeq,16h}^3$). This preliminary curve has been recommended for a quantitative risk assessment of environmental noise (20–22). Trend analyses (meta-regression analyses) revealed an estimate of the relative risk (RR) (calculated as OR of 1.08 (95% CI: 0.93-1.25) per 5 dB increase in noise level ($L_{Aeq,16h}$, range of category midpoints: 57.5-77.5 dB). This association was stronger in the subsample of subjects that had lived for at least 10-15 years in their dwellings (OR: 1.20 (0.98-1.46)).

Support for a relationship between road traffic noise and MI came from a recent Swedish case control study looking at the combined effects of road traffic noise and air pollution on the incidence of MI in subjects aged 45-70 years. Higher ORs were found for noise levels ($L_{Aeq,24h}$)

higher than 50 dB (23). For subjects in the highest noise category, an OR of 1.21 (0.83-1.77) was found compared to the reference category (<50 dB) for all MI cases after statistical control for air pollution. The study suggests that there are increased risks at noise levels even below 60 dB. When all noise categories greater than 50 dB were taken together, the adjusted OR was 1.12 (0.95-1.33) compared to the reference category. It was higher when subjects with hearing loss or exposure to other noise sources were excluded (OR 1.38 (1.11-1.71)).

Fig. 3. Exposure-response curve for the association between road traffic noise and MI



Source: Babisch (19).

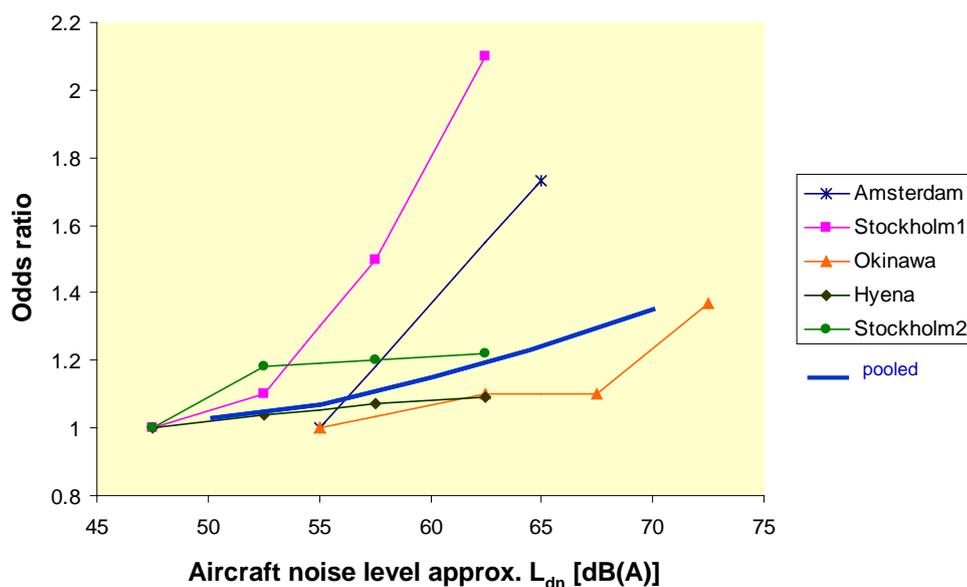
Aircraft noise

In mainly cross-sectional studies, higher mean blood pressure readings or a higher prevalence of cardiovascular disorders or medication intake were found in exposed subjects compared to those not exposed (7). Although the results of the single studies were not always significant, they showed a consistent tendency towards higher blood pressure in subjects with a higher exposure. In a prospective cohort study, the association between aircraft noise and the incidence of physically examined high blood pressure was investigated (24). Middle-aged men exposed to weighted energy-averaged levels (approximately L_{den}) above 50 dB had a higher risk (OR) of 1.19 (1.03-1.37) for the development of hypertension over the 10-year follow-up period compared with those less exposed. Older men were more affected. The increase in risk per 5 dB was 1.10 (1.01-1.19), showing a steady increase in risk with rising noise levels. In the multicentred Hypertension and Exposure to Noise near Airports (HYENA) study carried out around six European airports, a smaller significant increase in the risk of hypertension of 1.07 (1.01-1.13) for a 5 dB difference of aircraft noise during the night (L_{night}) was found (Jarup et al., 2008). A smaller OR was found for the weighted 24-hour noise indicator L_{den} of 1.02 (0.98-1.06) per 5 dB.

Five aircraft noise studies were considered for a pooled analysis (12,24–27). An exposure-response function was derived from data showing an RR (OR) of 1.06 (95% CI: 1.00–1.13) per 5 dB increase in the aircraft noise level (L_{dn} , range of category midpoints: 47.5-67.5 dB) (28). The pooled approximate curve is shown in Fig. 4. Difficulties in pooling the results are due to the fact that different criteria for the determination of high blood pressure were used, including systolic/diastolic blood pressure readings above 160/100 mmHg or 140/90 mmHg, self-reported

doctor diagnosed hypertension and antihypertensive drug medication. Since the pooled effect estimate is based on different studies with different noise level ranges, no clearcut level for the onset of the increase in risk can be given. It is, therefore, suggested that either $L_{dn} \leq 50$ (shown in Fig. 4) or, as a more conservative approach, $L_{dn} \leq 55$ dB should be used as a reference (OR=1) for quantitative risk calculations. This preliminary curve can for the time being be used for quantitative risk assessment (20,21).

Fig. 4. Exposure-response curve for the association between aircraft noise and hypertension



Source: Babisch & van Kamp (28).

Support for a relationship between aircraft noise and high blood pressure comes from new cross-sectional studies that have been recently published. A large study (29) looking at prescriptions for antihypertensive and cardiac drugs in subjects around a major German airport demonstrated exposure-response relationships, particularly, with noise exposure during the night. An Italian study (30) found 6.4 (1.5-11.4) mmHg systolic and 4.2 (1.0-7.3) mmHg diastolic higher diurnal mean blood pressure readings in subjects exposed to aircraft noise levels ($L_{Aeq,24h}$) above 65 dB compared to those less exposed (<60 dB). A new Swiss cohort study (31) demonstrated an increase in MI mortality with increasing level and duration of aircraft noise (L_{dn}). Subjects living in the >60 dB category had a 1.30 (0.96-1.76) higher hazard ratio for MI than subjects living in the reference category (<45 dB) after adjustment for air pollution (PM_{10}) and distance to a major road, which is an indicator of noise exposure and air pollutants related to road traffic. Air pollution in this study was not associated with MI.

Conclusions

Public health policies rely on quantitative risk assessment to set environmental quality standards and to regulate exposure to environmental noise sources in the communities. In accordance with the END (32), member states are currently assessing and documenting (by making strategic noise maps) exposure to environmental noise sources in their countries, including road, rail, aircraft and industrial noise. The END (Annex III) advises the use of dose-effect relations to

assess the effects of noise on populations. There is sufficient evidence that long-term exposure to community noise increases the risk of cardiovascular diseases. The effects were stronger when exposure modifying factors (room orientation, window opening habits, duration of residence) were considered. Thus, the question is no longer whether environmental noise causes cardiovascular diseases. It is, rather, what is the magnitude of the exposure-response relationship (slope) and the threshold (intercept) of the increase in risk. Based on comprehensive meta-analyses of epidemiological noise studies, preliminary exposure-response curves have been derived of the relationships between road traffic noise and the incidence of MI on the one hand, and aircraft noise and hypertension on the other, that can be used for environmental burden of disease assessments of the cardiovascular effects of community noise (21). Future research will have to look at possible gender differences in the effects of noise, the combined effects of different noise sources and the combined effects of noise and air pollution, particularly, with regard to road traffic since emissions come from the same source. Railway noise also needs more attention because of the increase in freight traffic, particularly at night (33).

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6. Calculating DALYs for cardiovascular diseases and sleep disturbance related to environmental noise using strategic noise maps: step-by-step guidance

Thomas Classen¹²

Introduction and objectives

Noise from road, rail and air traffic (transport noise), which makes up the major part of total environmental noise, affects a great number of people, especially in densely populated European countries. Due to its ubiquity and noise levels, and despite technological progress over time, transport noise has an important impact on public health. Nevertheless, the extent of this impact is hard to assess, especially when undertaking comparative health risk assessments of different environmental stressors.

In the EBoDE project, strategic noise maps (processed mainly in 2007 to meet the regulations of the END (1) in a totally new approach were used as input data for assessment of exposure to transport noise. These data from the first phase of END reporting are to a relatively high extent harmonized and comparable, especially for noise hot spots, between different countries.

While the availability of data from strategic noise mapping offers some opportunities, it also reveals some major limitations, particularly arising from the distribution of the population (displaying mostly hot spots) in countries. Specific guidance on how to assess and work with the data from strategic noise mapping is required which displays and discusses uncertainties. Such guidance could be helpful for countries outside the EU, where strategic noise maps may not exist as a result of differing regulations.

The following step-by-step-guidance was formulated to assist other EU member states as well as other countries, especially those in south-eastern Europe and the newly independent states, in methodology and data needs when calculating the EBD of environmental noise.

Step-by-step guidance

In this guidance, different steps to be taken when processing comparable and health risk assessments are presented. These steps follow the rules of good practice in EBD calculation, where information about substantial health outcomes, exposure levels of the population, reliable exposure-response functions and processing of health data are prerequisites. Additionally, the need for adequate communication of the risk and dissemination of the results addressing uncertainties and overall limitations is presented.

Step 1. Selecting health endpoints

In recent years, numerous health outcomes have been associated with exposure to environmental (especially transport) noise. Nevertheless, the evidence about measurable effects, or at least clear associations, is fairly good.

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Today, extensive international reviews and guidelines are available such as the *Night noise guidelines for Europe* (2), the *Good practice guide on noise exposure and potential health effects* (3) and *Burden of disease from environmental noise: quantification of healthy life years lost in Europe* (4).

Exposure to transport noise may cause sleep disturbance as well as annoyance, potentially leading to high blood pressure, ischaemic heart disease and increased incidence of MI (2,5–7). Transport noise exposure has also been linked with tinnitus (high exposure), effects on cognition (performance) and overall mental health. These health outcomes are all considered relevant in qualitative descriptions of the potential effects of transport noise. But for later EBD modelling, precise and evident knowledge about exposure-response relationships (see step 2) and the availability of valid health data (see step 4) are essential.

In the EBoDE project, high sleep disturbance (HSD) (7) due to overall transport noise and IHD due to road traffic noise with a specific focus on MI (5,6) were included as health outcomes (8).

Hypertension and related heart disease resulting from aircraft noise were not considered because in 2009 no significant or validated study or meta-analysis was available. Nevertheless, since associations (potential causal relationships) with aircraft noise are very likely and have been reported recently, this health effect may be considered in the near future (9). Astonishingly, no significant associations with hypertension and IHD have yet been identified for railway noise (10).

Effects on cognition (performance) in schoolchildren were excluded as well, as these are difficult to quantify and not considered a health outcome by, among others, WHO. Annoyance, especially severe annoyance, was not included for the same reason, even though there are strong associations with transport noise (3).

Step 2. Deriving exposure- response functions

EBD calculations are a quantitative method in comparative environmental risk assessment estimating DALYs as the burden of disease metric (see step 5). The availability of valid exposure-response functions linking environmental stressors to specific health outcomes with a high degree of evidence is, therefore, a prerequisite. Today, well-accepted exposure-response functions are available for sleep disturbance due to transport noise, MI due to road traffic noise and annoyance (not investigated here) due to transport noise (3,4).

Most of the exposure-response functions nowadays refer to L_{den} or L_{night} (see the formulae for estimating sleep disturbance below), but some still refer to L_{day} or $L_{day,16h}$ due to the study design they were once validated for (see polynomial for daytime noise and MI on page 15, Fig. 3).

For MI as one major outcome of IHD, the exposure-response functions (OR) refer to a meta-analysis by Babisch (5,6). Since there is no exclusive causal mechanism postulated specifically to MI, the OR for MI can be applied to all types of IHD (6) according to the following formula (5,6) (Fig. 5):

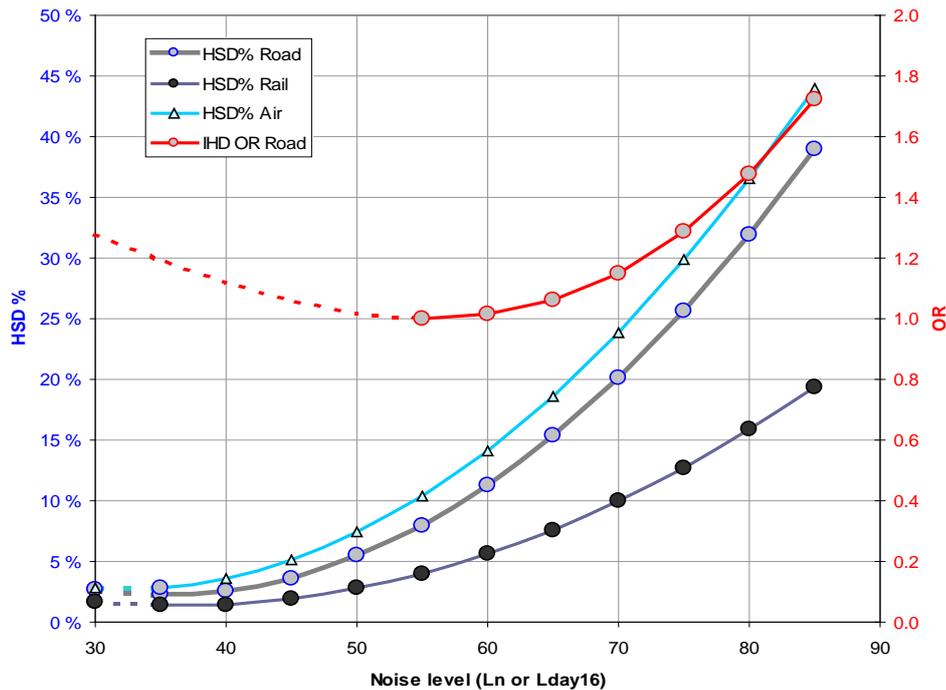
$$\text{OR} = 1.63 - 0.000613 \times (L_{\text{day},16\text{h}})^2 + 0.00000736 \times (L_{\text{day},16\text{h}})^3$$

as a linear term: OR per 10 dB = 1.17; 95% CI = 0.87-1.57

The function is valid for $L_{\text{day},16\text{h}}$ noise levels (0700-2300 hours) ranging from 55 dB to ~ 80 dB. Since no $L_{\text{day},16\text{h}}$ data are available from END reporting, the following easy formula can be used as a crude but practical tool for conversion (3,11):

$$L_{\text{day},16\text{h}} = L_{\text{den}} - 2.5 \text{ dB.}$$

Fig. 5. Exposure-response functions for HSD (blue axis) and IHD (red axis) for transport noise



Note. The OR for MI, applied for overall IHD, is only available for road traffic noise (red curve). (Dotted lines display the non-valid polynomial values outside the scope of the curves.)

Source: Hänninen & Knol (8).

The formulae applied to estimate HSD induced by transport noise are as follows. The exposure-response functions refer to an updated meta-analysis by Miedema & Vos (7) distinguishing between three categories of severity of sleep disturbance. The formulae below give a direct estimate of the percentage of people suffering severe disturbance to their sleep from noise as a function of L_{night} for each noise source:

road traffic noise:	$\% \text{HSD} = 20.8 - 1.05 L_{\text{night}} + 0.01486 (L_{\text{night}})^2$
rail traffic noise:	$\% \text{HSD} = 11.3 - 0.55 L_{\text{night}} + 0.00759 (L_{\text{night}})^2$
aircraft noise:	$\% \text{HSD} = 18.147 - 0.956 L_{\text{night}} + 0.01482 (L_{\text{night}})^2$

The formulae are valid in the range of L_{night} from 45 dB to 65 dB (maximum 70 dB) (see Fig. 5). Unfortunately, data from END reporting are currently only available for >50 dB, leaving a substantial gap at lower exposures (see step 3).

Step 3. Aggregating exposure data from country-specific strategic noise maps (if available)

The exposure metrics and their lower limits of reporting in the END strategic noise maps are:

- the weighted day-evening-night noise level (L_{den}) >55 dB, and
- the average eight-hour noise level during the night (L_{night}) >50 dB,

assessed separately for road, rail and air traffic noise. Using these metrics of equivalent noise levels, strategic noise maps help to identify noise hot spots and support policy-making for noise abatement.

From the first round of END reporting, carried out in 2007, noise exposure data per 5 dB category are available for most of the EU countries. These data concern:

- agglomerations with more than 250 000 inhabitants (separately for road, aircraft and railway traffic);
- roads outside agglomerations with more than 6 million vehicles per year;
- railways outside agglomerations with more than 60 000 trains per year;
- major airports with more than 50 000 air traffic movements per year (some separated for inside and outside agglomerations and in total).

These data have recently been aggregated and are available through the Noise Observation and Information Service for Europe (12). Via the web-based geographic information system user interface, data sheets can easily be downloaded in a format readable in, for example, Excel, and aggregated differentiated by country, region, city and noise source. These data are still to some extent being processed, as can be seen in an overview of the number and percentage of data reported to date (13,14).

So far, the data mandated by the END only cover a relatively small percentage of the population of the EU. But since strategic noise mapping is implemented in a fairly standardized manner (11), these data are representative for the subpopulations within the scope of the mapping.

The population coverage of the data for the countries included depends substantially on the degree of urbanization of countries, on the administrative boundaries (for example, the extent of cities) and on the location of the country (in the centre of the EU or on the periphery) and whether it is thus subject to transit influences. In consequence, the comparability of different countries is limited. The coverage also differs for the three noise sources addressed: it is much higher for air and railway traffic noise than for road traffic noise due to different densities of the traffic nets.

What can be done if data from strategic noise maps are incomplete?

During the EBoDE project, END reporting of many countries was complete for L_{den} but incomplete as regards data about L_{night} . To overcome this obstacle, the following formula was derived for conversion:

$$L_{den} = L_{night} + 7.5 \text{ dB.}$$

This formula is based on an expert judgement after first data-pooling and represented the best fit. There are, however, large differences, especially for conversion from L_{den} to L_{night} concerning an additional factor, since this factor ranges from +5 dB (highly urbanized) to +11 dB (including

rural areas) (compare (11)). Consequently, the additional factor +7.5 was chosen as a conservative factor, even though in some cases there might be an underestimation of real exposure. If conversion is really needed due to missing data, region- and country-specific noise profiles ought always to be assessed beforehand.

Before the noise indices L_{den} and L_{night} were introduced as noise metrics by the END, other noise metrics had been used such as L_{day} , $L_{day,16h}$ and $L_{Aeq,24h}$. Some of these metrics are still in use for specific questions or because of national legislation in certain countries, especially those outside the EU. Some of the exposure-response functions for health outcomes (such as MI) still relate to metrics other than L_{den} and L_{night} . For conversion of these different metrics, the European Commission Working Group on Assessment of Exposure to Noise produced a good practice guide with helpful background information and formulae (11). For countries outside the EU with differing noise metrics or missing data, this guide supplies relevant information and adjustments for exposure modelling.

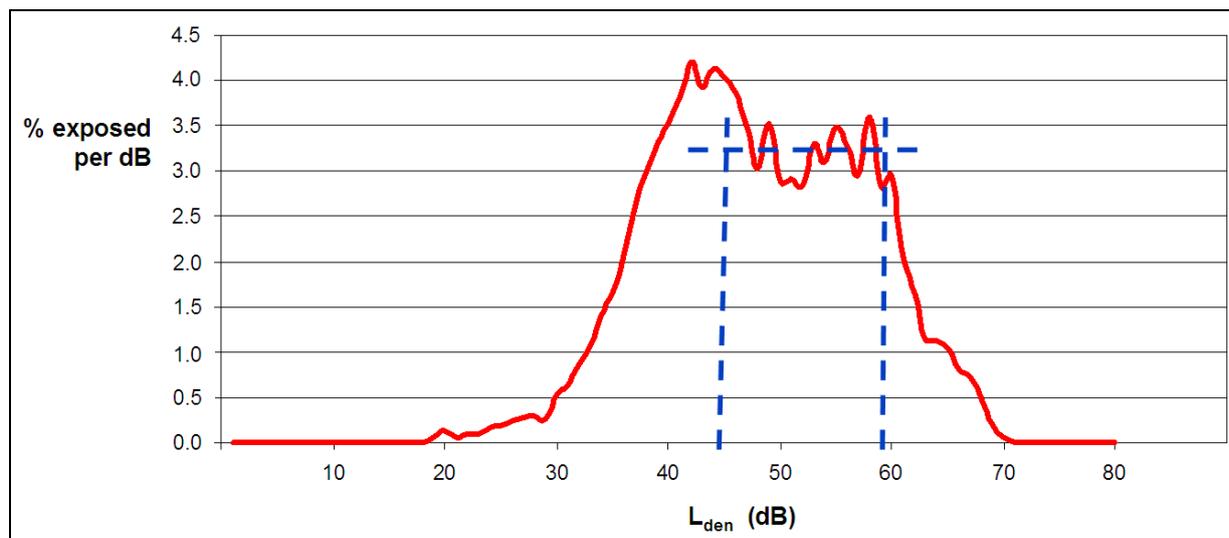
Results on exposures to lower noise levels than those required for the END strategic noise maps (see above) may have been automatically obtained in the strategic mapping but nonetheless need not be reported to the European Commission. Lower exposure categories are, however, still relevant considering health outcomes such as sleep disturbance (see step 2) or annoyance. To fill the gap between available and needed exposure data, a study assessing the health impact of environmental noise in Finland assumed a flat exposure distribution in the low-noise regime, assigning a constant prevalence below the lowest category reported (15) (Fig. 6). This crude assumption was discussed in a WHO meeting in October 2010 and was deemed to result in a conservative estimate of actual exposures in many contexts, while in some contexts an overestimation of the low-exposure prevalences might also result, depending on the population and the type of noise source addressed.

What can be done if no (strategic) noise maps are available?

Strategic noise maps from the first round of END reporting only cover a variable, but relatively small, proportion of total national populations and are mainly valid for hot spots (high exposure areas) only. The measuring and modelling process for generating these maps (if meant to mirror the actual situation as accurately as possible) is a time- and money-consuming effort (11). Nevertheless, pending more extensive exposure data coverage, the first approximations based on a generalized approach can be used to obtain rough estimates of actual exposure prevalences (15); for more detail see Chapter 10 in this booklet, as outlined below.

- *For (smaller) urban areas.* In this approach, exposure distributions (percentage of the population exposed per dB category) for, for example, L_{den} are determined for representative cities or towns in different size brackets by reference to published data or by ad hoc modelling. Expert judgement might be needed in making adjustments to local contexts. Finally, the distributions are generalized to all cities in the same size bracket.
- *For (minor) roads or railways.* Similarly, exposure distributions are derived by sampling representative road/railway districts, for example from districts already mapped in other countries. The distributions may be applied to all acoustically similar road/railway districts in the country under consideration.

Fig. 6. Modelled L_{den} distribution of road traffic noise exposure for the population of Helsinki^a



Source: adapted from van den Hout et al., cited by Kuusisto (15).

^a The nearly flat regime between 45 dB and 60 dB has been enhanced (dotted blue lines).

- *For (minor) airports.* An analogous approach can also be applied to airports. For example, foreign airports can be sampled that are of similar size and location (relative to residential areas) that have already been noise-mapped, or the average distribution of exposure to noise emanating from airports in each size bracket can be used by consulting EU-wide END data. Optionally, the results might be adjusted based on, for example, the number of movements.

Apart from these approaches, a first step is to assess whether other data indicating or serving as a proxy of exposure to noise can be obtained, such as traffic and population density, air quality data or outcome-based information (such as self-reported sleep disturbance due to transport noise).

Step 4. Processing health data

After assessment of exposure, baseline health data for the selected outcomes should be obtained as another input for EBD modelling. The required scale of health data depends on the overall question of the study (regional, national or international comparison). The best adjustment can always be made by deriving health data on a national, subnational or even district level, since data from END reporting cover particularly the city level. In the EBoDE project, however, availability of information about national health outcomes was sufficient due to the country comparability approach. These data are available in the harmonized health statistics database (Health statistics and health information systems: Disease and injury country estimates) held by WHO, providing country-specific data for deaths and for summary measures of population health from burden of disease studies such as years of life lost due to premature death (YLL), years of life lived with disability (YLD) and DALYs from the Global Burden of Disease (GBD) study of 2004 (16,17).

For IHD,¹³ this harmonized health statistics database can be used, assuming that in the countries in WHO's epidemiological subregion Eur-A,¹⁴ 57% of deaths and 7.8% of YLDs from IHD are

¹³ ICD-10: I20-I25 (19); GBD code: U 10 (17).

from MI.¹⁵ Health data (especially for mortality) can be obtained from national and local health authorities and statistics, and should be preferred because of the very rough assumptions for the proportion of MI in IHD for the whole Eur-A region.

No additional health data are necessary for HSD since the percentage of people affected is directly calculated and transferred into concrete numbers. HSD is best associated with primary insomnia.¹⁶

Step 5. EBD calculation

EBD calculation aims at showing one number of the burden of disease attributable to one specific environmental stressor (18). This EBD is expressed in DALYs, which are calculated by summing YLDs and YLLs.

A detailed overview of this method is presented in Prüss-Üstün et al. (18). Different approaches in EBD modelling can be derived from the EBoDE Working Group.

RR must be calculated separately for each exposure category due to the nonlinear exposure-response functions (see step 2). Since noise level reporting regularly covers 5 dB categories, the mid-values of the 5dB categories (for example, 50-54.9 dB → 52.5dB) can be inserted in the nonlinear polynomials as a feasible simplification. The steps for calculation are set out below.

For *IHD*, the OR (a good approximation for the RR) is first calculated in each noise category. In the second step, an average OR is calculated by weighting the OR in each category by the number of people exposed. Finally, the exposure prevalence-weighted average OR and the total fraction of the population exposed (f) are inserted in the usual formula for the population-attributable fraction as proposed in the EBD approach:

$$PAF = \frac{f \times (RR - 1)}{f \times (RR - 1) + 1}$$

Finally, the IHD-attributable EBD is calculated by multiplying the population-attributable fraction with the burden of disease values for IHD as obtained from WHO or national health statistics: $EBD = \text{population-attributable fraction} \times \text{burden of disease}$.

For *HSD*, the number of HSD cases is first calculated for each exposure category by inserting the category mean in the exposure-response functions and by multiplying the exposure prevalence (percentage) that results with the number of people exposed in that category. By summing all exposure categories, the total number of people with HSD is estimated. Finally, this number is inserted in the YLD calculation, where the duration of HSD (being a prevalence indicator) is one year.

¹⁴ WHO epidemiological subregions in Europe: *Eur-A*: Andorra, Austria, Belgium, Croatia, Cyprus, the Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, the Netherlands, Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

¹⁵ ICD-10: I21; GBD code: U107seq1, not available separately from WHO's health statistics and health information systems: Disease and injury country estimates database (17).

¹⁶ ICD-10: F51; GBD code: U 094.

For calculation of DALYs, disability weights were chosen as follows:

- acute MI as a proxy for IHD (GBD code U 107):
disability weight = 0.23 (CI: 0.1-0.4)
- HSD:
disability weight = 0.07 (CI: 0.04-0.10, disability weight values derived from WHO's *Night noise guidelines for Europe* (2)).

Calculations of DALYs in line with most recent estimates by WHO are best done without consideration of lag, discounting or age-weighting. For better comparability, DALYs may be presented per million inhabitants per year. Time trends are ignored for the present purpose.

Step 6. Communication/dissemination of the results

EBD modelling offers some great advantages in terms of easier comparability of different health outcomes and, especially, of different environmental stressors by just presenting one number (the value of the DALY metric) at the end. This may be very helpful (provided the concept is properly understood) in decision- and policy-making processes regarding, for example, potential interventions. On the other hand, EBD modelling has some weaknesses resulting from uncertainties and other limitations arising from study designs. Consequently, there is always a strong need for adequate risk communication addressing the uncertainties and limitations in presentations of the results of EBD calculation.

Some of the limitations of the EBD method itself, and specifically of using END strategic noise maps, are listed and discussed below with respect to the challenges in the EBoDE project, which can generally be applicable to all END-based calculations.

In the EBoDE project, the differences between countries indicate some major limitations due to:

- incomplete exposure data from END reporting (some information was still missing at the end of 2010);
- different population and traffic densities in countries as a result of the degree of urbanization, administrative boundaries (such as the extent of cities), location of the country (central or peripheral) and resulting transit influences;
- diverse options and methodological approaches for generating strategic noise maps as presented in END and the *Good practice guide for strategic noise mapping and the production of associated data on noise exposure* (11);
- the fact that exposure data reported in the first stage of END reporting represent only hot spot" where noise levels are supposed to be much higher than in the countryside (even when noise distributions outside agglomerations are being considered).

The resulting DALYs are, therefore, an underestimation of the total burden on a country but would probably overestimate the risks if first extrapolated to the whole national population and then normalized per million inhabitants. Country comparability is consequently affected by the variations in representativeness of the results owing to the higher population coverage in the first round of END reporting in densely populated countries.

Apart from country-specific variability in END data, the DALYs calculated in the EBoDE project almost entirely (96%) resulted from morbidity due to HSD. DALYs in this respect are very sensitive to changes in disability weight (CI 0.04-0.10) and less sensitive to minor changes

in exposure levels (due, for example, to other constants used for conversion of L_{den} to L_{night}) or exposure-response functions. Further uncertainties resulted from missing or invalid exposure-response functions for certain transport sources (such as air and railway traffic when considering IHD) and for other symptoms of potential health effects such as hypertension or annoyance. In this respect, the results of EBD studies to be produced in the near future are highly likely to underestimate the burden of disease related to transport noise. On the other hand, overestimation could result from potential double-counting of cases or when summarizing multiple numbers without exact knowledge of multicausal effects (such as annoyance and sleep disturbance).

Another limitation of the calculation stems from disregard of several behavioural and acoustical factors affecting noise exposure indoors (such as the location of bedrooms, window opening habits, and the insulation of windows). Likewise, exogenous variables affecting those factors (such as climatic conditions, socioeconomic status and house ownership) were ignored.

Last but not least, one limitation arises from the fact that this guidance only considers traffic noise. Exposure to occupational noise, neighbourhood noise and other noise sources, such as those resulting from leisure-time activities (for example, sports, discotheques or listening to music via ear phones), were not taken into account despite their high potential impact on, for example, hearing. This reflects inhomogeneous data availability in terms of exposure, groups at risk and morbidity of health outcomes.

Nevertheless, the method of EBD modelling presented in this guidance using strategic noise map data from END reporting can become a compelling alternative to the former calculations based on vague and rough overall estimates of transport noise. Even more advantages can be expected from the second round of END reporting in 2012, which will account, for example, for agglomerations with more than 100 000 inhabitants, resulting in much higher coverage of the total population. As announced at a WHO meeting in October 2010 in Bonn, the EEA is giving emphasis to optimizing data transfer in terms of usability for health-oriented calculations such as EBD modelling.

Conclusions and recommendations

This step-by-step guidance presents a new, challenging and hopefully useful tool for EBD modelling using data END reporting. Capacity-building, especially in the new EU member states, south-eastern European countries and the newly independent states, is essential to reduce the gap between the countries in the region and to promote the quantification of environment and health topics such as the impact of noise on health. Professional networks on noise and health such as the European Network on Noise and Health (ENNAH) and the International Commission on Biological Effects of Noise (ICBEN) can serve as a channel for the transfer of knowledge and a platform for cooperation in capacity-building in the area of risk assessment of environmental noise. In addition, the Common Noise aSSessment methOdS (CNOSSOS-EU) framework which was developed by the Joint Research Centre supports the European Commission Directorate-General for the Environment in the implementation of END to improve the reliability and comparability of strategic noise maps in EU member states. Special emphasis should be put on cooperation between CNOSSOS-EU and WHO-ECEH in harmonizing the assessment of exposure to and the health risks from environmental noise, particularly in the context of the forthcoming revision of END.

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7. Process, results and lessons of the EBoDE project: calculating the burden of cardiovascular diseases and sleep disturbance in six countries

*Thomas Classen*¹⁷

Introduction

In this section, the methods to calculate the burden of cardiovascular diseases and sleep disturbance in six countries are briefly described. The previous chapter gives a detailed overview of the methods used for noise EBD modelling in the EBoDE project.

Methods

Selecting health endpoints

Exposure to transport noise may cause sleep disturbance as well as annoyance, potentially leading to high blood pressure and increased incidence of myocardial infarction (1–5). Such exposure has also been linked to effects on cognition (performance) and overall mental health (6).

As health end-points, HSD (3) and IHD with a focus on MI (1,2) were included. Hypertension and related heart disease due to aircraft noise and effects on cognition (performance) were not considered as they are difficult to quantify. Neither is severe annoyance, as annoyance is not considered a health effect by (among others) WHO.

Exposure data aggregation

The exposure metric used is the weighted day-evening-night level (L_{den}) and the average eight-hour noise level during the night (L_{night}) in dB, assessed separately for road, rail and air traffic. These indices are suggested by the END.

From the first phase of END reporting, carried out in 2007, noise exposure data per 5 dB band have been available for most of the EU countries. These data concern:

- agglomerations with more than 250 000 inhabitants (separately for road, rail and air traffic);
- roads outside agglomerations with more than 6 million vehicles/passages per year;
- railways outside agglomerations with more than 60 000 trains/passages per year;
- major airports with more than 50 000 air traffic movements/flights per year (some separated for inside and outside agglomerations and in total).

These data have recently been aggregated and are still to some extent being processed (7,8). So far, they only cover a relatively small percentage of the EU population. The population coverage of the data for the countries included depends substantially on the degree of urbanization of countries, on the administrative boundaries (such as the extent of cities) and on the location of

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the country (whether it is in the centre or on the periphery of the EU) and the resulting transit influences. In consequence, the comparability of the countries is limited. Additionally, the aggregated data used until the end of 2009 for Belgium only included Flanders and for France only the major agglomerations (dominated by Paris). END reporting by many of the countries was only complete for L_{den} but incomplete for L_{night} , necessitating the use of a conversion formula:

$$L_{den} = L_{night} + 7.5 \text{ (expert judgement after first data-pooling (9)).}$$

Exposure– response functions

The formulae applied to estimate HSD induced by transport noise are as follows. The results give the percentage of people whose sleep is severely disturbed as a function of the exposure metric (L_{night}) for each noise source (3):

road traffic noise:	$\%HSD = 20.8 - 1.05 L_{night} + 0.01486 (L_{night})^2$
rail traffic noise:	$\%HSD = 11.3 - 0.55 L_{night} + 0.00759 (L_{night})^2$
aircraft noise:	$\%HSD = 18.147 - 0.956 L_{night} + 0.01482 (L_{night})^2$

The formulae can be applied in the range of L_{night} from 45 dB to 65 dB (maximum 70 dB), but END data are currently only available for >50 dB.

There is no exclusive causal mechanism postulated specifically for MI. The OR for MI has, therefore, been applied to all types of IHD (2) according to the following formula (1,2):

$$OR = 1.63 - 0.000613 \times (L_{day,16h})^2 + 0.00000736 \times (L_{day,16h})^3$$

The function is valid for $L_{day,16h}$ noise levels (0700 to 2300 hours) ranging from 55 dB to ~ 80 dB. Since no $L_{day,16h}$ data are available from END reporting, the following approximation was used as a crude but practical tool for conversion (9,10):

$$L_{day,16h} = L_{den} - 2.5 \text{ dB.}$$

Health data

No health data were necessary from WHO for HSD since the percentage of people affected was given by the exposure-response functions.

For IHD, the harmonized health statistics database (11) held by WHO (GBD code U 107, assuming that in Eur-A countries 57% of deaths and 7.8% of YLDs from IHD are for MI) was used, providing country-specific data (deaths, YLLs, YLDs and DALYs) for 2004 (5). The data were obtained in discounted/age-weighted and undiscounted/un-age-weighted format.

EBD calculation

EBD calculation was processed as described by the EBoDE Working Group (12). Exposure category-specific calculation was necessary for environmental noise due to the nonlinear exposure-response functions. Since END reporting covers 5 dB categories, the mid-values of these categories (50-54.9 dB → 52.5 dB) were inserted in the exposure-response functions formulae to simplify the calculation of ORs and the percentage of people with HSD. The attributable fraction was assumed directly by multiplying the exposure prevalence (%) for that

results from calculation of number of HSD cases per each exposure category with the total number of people exposed for HSD and by using the proposed formula for calculation of the attributable fraction in EBD.

For calculation of DALYs, disability weights were chosen as follows:

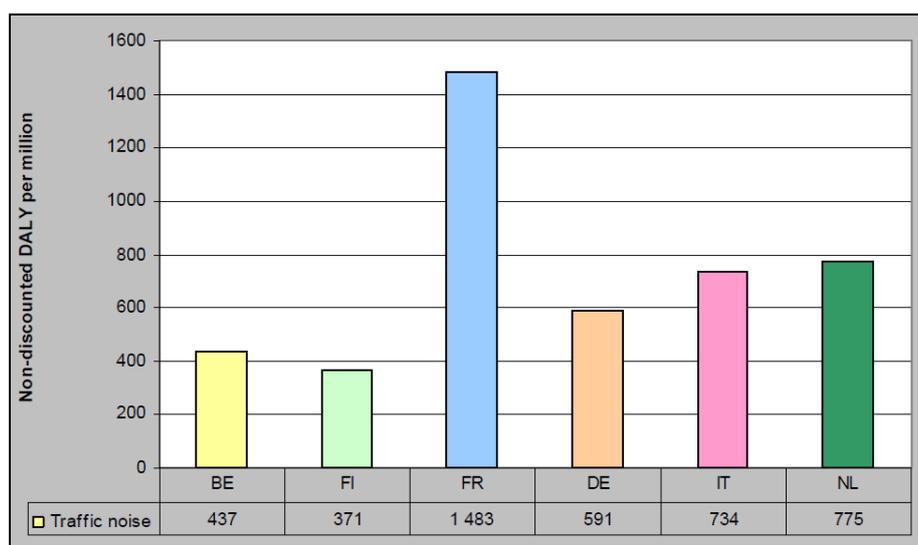
- acute MI as a proxy for IHD (GBD code U 107):
disability weight = 0.23 (CI: 0.1-0.4)
- high sleep disturbance:
disability weight = 0.07 (CI: 0.04-0.10, values derived from *Night noise guidelines for Europe* (6)).

Results were calculated both as standard discounted (3%) and age-weighted estimates with lag, and without discounting or weighting (shown below). For better comparability, DALYs were expressed per million inhabitants per year. No time trend was postulated even though in most countries noise levels are still increasing.

Results

Since so many people are exposed to and affected by transport noise, the total associated disease burden is substantial despite relatively small disability weights. Nevertheless there are numerous differences between the countries. DALYs range from ~400 per million inhabitants per year in Finland (less densely populated and highly urbanized, few cities with more than 250 000 inhabitants) to ~1500 DALYs per million inhabitants per year in France (due to different noise modelling and the fact that only data for the greater Paris area were available) (Fig. 7). More than 95% of the total burden is due to HSD.

Fig. 7. Undiscounted, non-age-weighted DALYs per million people per country



Source: Hänninen & Knol (12).

Discussion

The differences between the countries addressed indicate some major limitations due to incomplete exposure data from END reporting (for Belgium, data were only available for the Flanders region), and to different population and traffic densities in the countries. A substantial limitation results from the fact that exposure data reported in the first stage of END reporting represent only hot-spots where noise levels tend to be much higher than in the countryside. The DALY figures are, therefore, an underestimation of the total burden for each country but would overestimate the risks if first extrapolated to the whole national population and then normalized per million inhabitants. Consequently, country comparability is affected by variations in the representativeness of the results due to higher population coverage in the first round of END reporting in densely populated countries.

Of the calculated DALYs, nearly all (96%) result from morbidity due to HSD. They thus depend sensitively on the chosen values of disability weights (for HSD, CI: 0.04-0.10) compared to the more moderate uncertainties in exposure assessment (for example, due to conversion of L_{den} to L_{night}) and even in the exposure-response functions. Further uncertainties result from missing or invalid exposure-response functions for certain transport sources (such as air and rail traffic when considering IHD) and for outcomes such as hypertension or annoyance that are ignored at present. In this respect, the results are very likely to underestimate the burden of disease related to transport noise.

Despite the numerous limitations of using END data for EBD modelling of transport noise in the EBoDE project, a great opportunity was opened due to an EU-wide, standardized exposure assessment, increasing comparability between countries. This comparability will be enhanced by the second round of END reporting in 2012, which will take into account, for example, agglomerations with more than 100 000 inhabitants, resulting in a much higher coverage of the total population.

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8. Dealing with uncertainties in EBD assessments

Danny Houthuijs,¹⁸ Anne B Knol¹⁸

Introduction

EBD estimates allow policy-makers to appraise, compare and prioritize different environmental health impacts or possible intervention measures. EBD estimates have various uncertainties and assumptions that are not often made explicit. This chapter presents a typology to identify and characterize uncertainties, with examples relating to environmental noise.

Typology of uncertainty and its relevance for environmental noise

Knowledge about environmental health impacts is incomplete and a variety of assumptions need to be made for burden of disease calculations. A typology of uncertainties can be used to systematically identify and describe uncertainties.

Table 2. Typology of uncertainty

Uncertainty characterizations	Categories
Location: the location at which the uncertainty manifests itself in the assessment	<p><i>Context</i>: definitions and boundaries of the system being assessed</p> <p><i>Model structure</i>: structure and form of the relationships between the variables that describe the system</p> <p><i>Parameters</i>: constants in functions that define the relationships between variables (such as RR or severity weights)</p> <p><i>Input data</i>: input data sets (such as exposure level, demographic data and incidence data)</p>
Nature: the underlying cause of the uncertainty	<p><i>Epistemic</i>: resulting from incomplete knowledge</p> <p><i>Ontic</i>: process variability: resulting from natural and social variability in the system</p>
Range: expression of the uncertainty	<p><i>Statistical (range + chance)</i>: specified probabilities and specified outcomes</p> <p><i>Scenario range + "what if"</i>: specified outcomes, but unspecified probabilities</p>
Recognized ignorance	Unknown outcomes, unknown probabilities – uncertainties are present, but no useful estimate can be given
Methodological unreliability	Methodological quality of all the different elements of the assessment; a qualitative judgment of the assessment process which can be based on, for example, its theoretical foundation, empirical basis, reproducibility and acceptance within the peer community
Value diversity among analysts	Potential value load of assumptions which inevitably involve (to some degree) arbitrary judgments by the analysts

Source: Knol et al. (1).

The different categories of location of uncertainty are discussed below. The remaining characteristics are other dimensions of uncertainty and are not explicitly discussed here.

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Contextual uncertainty refers to the boundaries of the assessment, the definitions used and the selected health endpoints and exposure metrics. With respect to the burden of disease for environmental noise, examples of contextual uncertainty are the choice of DALY for EBD calculations instead of other health summary measures (such as quality-adjusted life-years, health-adjusted life-year, disability-adjusted life expectancy and health-adjusted life expectancy), the use of equivalent noise levels (L_{den} , L_{night} and $L_{Aeq,16h}$) instead of event-like metrics (L_{Amax} , SEL), and the exclusion of hearing impairment, cognition and annoyance and the expansion from MI to IHD. Sensitivity and decision analysis can help to identify which sources mainly affect the final results.

Model structure uncertainty relates to the causal structure of the system modelled. The relatively small impact of environmental exposures on health makes it often difficult to assess whether there is a threshold level or whether the dose-response relationship is linear or nonlinear. This is the case for cardiovascular and cognitive outcomes in relation to noise. In addition, there is incomplete understanding of the potential joint effects of exposure to noise related to road traffic and air pollution on these outcomes. Model structure uncertainty is often epistemic (related to incomplete or contradictory knowledge); more research could increase understanding and possibly reduce uncertainty. It is essential to document the assumed model structure in a transparent way, to explore and document the existence of limitations and other viewpoints, and to reflect on the consequences for the robustness of the results.

Parameters are used to describe relations between variables. Uncertainty can be introduced by, for example, differences in study design and/or by measurement error (methodological unreliability) which can affect outcome parameters such as an RR. It can be debated whether specific RRs can be extrapolated to other regions, time periods, health endpoints or population subgroups (recognized ignorance: we know what we don't know). Average population sensitivities and attitudes might differ between countries (an example of ontic process variability) which is relevant for the application of generalized dose-response relations for annoyance and self-reported sleep disturbance. Normative parameters such as severity weights are generally based on the judgement of health scientists. They are subjective interpretations of a number for which no true value exists. The value is likely to depend on who is being asked (ontic normative uncertainty) and on the way the effects are presented and the valuation method applied (methodological unreliability). An example is the relative large range for the severity weight for severe annoyance and severe sleep disturbance (0.01-0.12). Parameter uncertainty (and input data uncertainty, see below) is commonly quantitatively assessed through the use of statistical analyses (often based on CIs of parameters). For parameters for which various interpretations could exist (such as severity weights), sensitivity and decision analyses in combination with transparent reporting can be applied.

Uncertainty in input data may relate to various factors, such as the lack, inaccurate assessment or extrapolation of data. Exposure and disease data are the most common input data sets used for EBD calculations. Noise exposure data are only available for a limited percentage of the population (which differs between countries), mainly situated in agglomerations. In addition, no information is offered for the lower exposure categories (relevant for annoyance and sleep disturbance). For IHD incidence and heart attack rates, there is only scarce comparable data in European countries. Background disease data are regularly only available for highly aggregated levels, making input data for local assessments more uncertain.

The use of a typology may assist a structured dialogue between scientists and stakeholders to achieve a common understanding of the uncertainties and their importance.

Conclusions

Alertness in relation to uncertainties and a structured approach to the assessment and the communication of uncertainties can lead to a more balanced interpretation of the results of EBD assessments. A typology of uncertainties can be used systematically to identify and describe key uncertainties.

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9. Usefulness of strategic noise maps as exposure data for estimating the environmental burden of disease from environmental noise

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Introduction

Some European countries have made estimates of the burden of disease due to noise in the context of the EBoDE project (1). These estimates are mainly based on exposure data produced in the context of the first round of strategic noise mapping in Europe, as required by the END.

The EEA is currently assessing the data on noise that have been collected by EU countries in the first round of noise mapping in Europe for major agglomerations and major roads. They will repeat the exercise in the following round for smaller agglomerations and lesser roads. These data seem quite attractive for researchers working on noise and health issues, but they must be analysed and critically viewed, case by case. Evaluation and analysis of the strategic noise maps and noise exposure data prepared by the member states is an essential step before estimates can be made of the burden of disease in Europe due to environmental noise.

Evaluation of the usefulness of strategic noise maps as exposure data

As required by the END, strategic noise maps and action plans should be produced by the EU countries on a five-yearly basis, starting from 2007. Strategic noise mapping allows for the assessment of trends in noise exposure in Europe and of the efficiency of action plans and community policies.

From the first round of noise mapping in Europe, it is evident that noise exposure data that become available differ in relation to: definition of agglomerations, relevant year, quality of geographical and topographical data, availability of meteorological data, quality and extent of noise source data, quality of demographic data, methods of assigning noise levels to buildings, noise calculation methods, software implementation of each noise calculation method and software settings (2). These data have recently been aggregated by the EEA and are still, to some extent, being processed. So far they only cover a relatively small percentage of the EU population ($\approx 20\%$), as the END only required data from the biggest agglomerations (with over 250 000 inhabitants) to be gathered during the first round of strategic noise mapping. A progressively greater coverage of the population is foreseen in the next rounds of noise mapping as smaller agglomerations will also be mapped.

In order to evaluate the usefulness of strategic noise maps as data providers for exposure assessment purposes, several issues need to be addressed relating to data quality and evaluation of population exposure, as described below.

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Data quality

The following issues relate to the quality of data.

1. *Incompleteness of the data.* Some EU countries reported fairly complete noise exposure data sets, as required by the END, but others provided largely incomplete data which could hardly be used to characterize adequately the population's exposure to environmental noise. The range of DALYs differs between countries, from 360 DALYs per million inhabitants in Finland (less densely populated and highly urbanized, very few cities with more than 250 000 inhabitants) to 1900 DALYs per million people in France (only data from the greater Paris area were available). These differences indicate some major limitations due to incomplete exposure data from END reporting and to different population and traffic densities in the countries (1).
2. *Approximate estimation of number of people exposed.* According to END requirements, the data to be sent to the European Commission on the estimated number of people exposed should be indicated in hundreds. It is not always obvious, therefore, what the real number of exposed people is and sometimes a guess had to be made. Rounding figures to the nearest 100 means that the real numbers are not clear, yet quite a few authorities reported the numbers in units of a hundred (3).
3. *Differences between agglomerations.* The difference between agglomerations in the United Kingdom and those in other countries is striking: almost all the inhabitants of British agglomerations fall into an exposure category between 60 dB and 64 dB. Model calculations showed that if for residential streets where no data were available a relatively high traffic density is assumed (as is the case in the United Kingdom), the effect could very well be a peak of exposure in the 60-64 dB noise band (3).
4. *Estimation of exposure in quieter areas.* According to analyses of data from the first round of noise mapping in Europe, it seems that cities with high percentages of people exposed to noise levels above 55 dB L_{den} also present a high ratio of noise exposure in the noise band of 60-64 dB over that of 55-59 dB. This could be attributed to the way the modelling has been done: models which only took into consideration the major roads, including in agglomerations, usually resulted in an underestimation of exposure in quieter areas (due to local low traffic roads being ignored), so the populations are usually reported in the lower bands, with a ratio of lower than one. Those which included a reasonable approximation of all roads obtained a ratio greater than one, because buildings near roads experience high levels of noise and only a few buildings were screened to the point where they showed levels of under 60 dB (3).
5. *Estimation of exposure level versus method used.* The absolute levels of exposure depend to some extent on the methods of calculation used. Unfortunately, the requirement in the END (article 6.2) to demonstrate equivalency between national methods and the interim methods has not been met. In several cases the interim methods have been used, especially in those countries which did not have their own assessment methods (3).

Evaluation of population exposure

A second important issue is how population exposure was evaluated, since there is no standardized method for measuring it. The *Good practice guide for strategic noise mapping and the production of associated data on noise exposure* (4) made a number of recommendations regarding the assessment of population exposure based on the type of data available within each country. However, the approaches suggested fall far short of a standardized methodological approach. The following are salient points deserving special attention.

1. The scope of the noise exposure assessment is intended to cover every citizen and every road. It is only for efficiency reasons that the assessment started with densely inhabited areas. Definitions of agglomerations vary between the countries, but as long as the definition is kept the same over the years, trends in exposure can be analysed.
2. The population coverage for the countries included so far depends substantially on the level of urbanization, on the administrative boundaries (such as the extent of cities) and on the location of the country (whether it is in the centre or on the periphery of the EU) and the resulting transit influences. In consequence, comparability of the countries is limited (1).
3. The END does not explicitly state whether population exposure should be assessed at the individual level or at the level of individual buildings. It allows for both, and both approaches have been used to estimate human exposure from noise-mapping studies, as documented in the literature (5,6).
4. The END reporting mechanism requires the number of dwellings in specific exposure brackets to be reported to the nearest hundred. Rounding the figures indicates the level of uncertainty that is considered to be acceptable. With the standard receiver height of 4 m, the allocation of dwellings to the calculated exposure in a receiver point is dubious and leads to significant inconsistencies.
5. The END requires the number of citizens exposed to be assessed. This is carried out through assessment of exposure per dwelling and average occupation per dwelling. Such an approach leads to inconsistencies between countries, because the strategies for attributing noise levels and people to dwellings differ between them.
6. Generally, exposure levels are calculated at grid points and equal noise level contours are then drawn between grid points by means of interpolation. Then, in a geographic information system, the number of dwellings in the area between two contours is counted. This approach leads to inconsistencies in the assessment of the most exposed façades. Alternatively, some modellers compute the exposure of every façade and allocate the highest exposure to the dwelling under concern. Differences in these approaches lead to inconsistencies.
7. Population exposure is likely to be overestimated to a significant degree if the assessment is based on the individual. By counting individuals living in a particular household, the assessment method assumes (particularly during the night) that all individuals living in a particular household are exposed to the noise level at the most exposed façade of the building, which is highly unrealistic. Moreover, many people leave the cities at the weekends, but no account is taken of the migrant and transient population when estimating population exposure (7).
8. There is a strong limitation resulting from the fact that exposure data represent only hot-spots where noise levels tend to be much higher than in the countryside. The results from the calculations thus underestimate the total burden of a country, although they may overestimate the risks when applied to the whole population of a country (as done when normalized per million inhabitants) (1).
9. A further limitation relates to individual behavioural and acoustical factors affecting noise levels indoors (such as regular location of bedrooms, window opening habits and sound insulation) and exogenous variables affecting those factors (such as climatic prerequisites and house ownership) (1).

10. The END does not require any assessment of the percentages of people suffering annoyance or severe annoyance or whose sleep is highly disturbed. These numbers can, however, play a role when priorities for action plans are set and when health effects are assessed. The translation from exposure to effect is done in various ways.
11. The lack of accurate noise exposure data is a major hindrance in making accurate estimates of the burden of disease. If L_{den} can be used in place of L_{day} , the noise-mapping data for the END can be used but exposure data will still be sparse from the WHO Eur-B²⁰ and Eur-C²¹ epidemiological subregions. Extrapolation of exposure data from Eur-A to Eur-B and Eur-C countries might be problematic because the level of noise exposure of the populations might vary considerably between these subregions (8).
12. It would appear important that guideline limit values are set by the EU for both L_{den} and L_{night} . In the absence of these values, it is extremely difficult to assess adequately the extent of dose–effect relationships within and between countries (7).

Review of the implementation of END noise mapping

In December 2008, Milieu Ltd, Risk and Policy Analysis Ltd (RPA) and the Netherlands Organisation for Applied Scientific Research (TNO) were commissioned by the European Commission Directorate-General for the Environment to undertake a review of the experiences of member states in implementing the END (9). The project responds to Article 11 of the Directive, which requests an assessment of implementation. The amendments and solutions summarized below have emerged from an extensive review of EU countries' experiences with implementing the END, including both a questionnaire survey and follow-up interviews with relevant officials at national and regional levels.

Proposed amendments and solutions linked to population exposure

The following are some problems that have come up, together with proposed solutions.

Dose–effect relations. Two countries requested additional guidance on the interpretation of the dose–effect relations used to estimate the effect of noise on populations. The proposed solution is to provide additional guidance on dose–effect relationships.

Population exposure. A number of countries called for a common methodology with which to measure exposed populations. Two solutions proposed are: (i) to organize a workshop to assess methods and exchange best practice, and (ii) to develop a standard EU methodology for calculating exposed populations.

Multiple exposure. One country questioned how to display noise from multiple sources in noise maps (multiple exposures). A review of strategic noise maps showed that, in general, countries did not generate multiple exposure maps. In terms of their value to the public, such maps are useful in that they provide an overview of total exposure and facilitate interpretation of the noise situation at any one location. The solution proposed was to include a methodology for

²⁰ WHO Eur-B epidemiological subregion comprises Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Georgia, Kyrgyzstan, Montenegro, Poland, Romania, Serbia, Slovakia, Tajikistan, the former Yugoslav Republic of Macedonia, Turkey, Turkmenistan and Uzbekistan.

²¹ WHO Eur-C epidemiological subregion comprises Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, the Republic of Moldova, the Russian Federation and Ukraine.

calculating multiple exposures in the *Good practice guide for strategic noise mapping and the production of associated data on noise exposure* (4).

Example: usefulness of the Swedish END maps for noise and health research

In Sweden a study was carried out to investigate the usefulness of END maps for health studies (10). The study was performed for over 2496 subjects living in the three major cities of Gothenburg, Malmö and Stockholm. Data on noise annoyance were provided by a national environmental health survey. L_{den} was assessed at the most exposed façade of participants' dwellings. Noise map information, together with survey information on apartment orientation towards nearby roads, was used to locate the dwelling within a building. This study briefly describes a methodology for assessing individual noise exposure. The authors presented several real noise-mapping examples, and showed how individual noise exposure can be assessed and also how people can be assigned to appropriate noise level bands. They concluded that Swedish END noise maps constitute an important source of potentially useful information for noise and health studies. The results of the study suggest that this information could be used to obtain valid assessments of individual noise exposure, at least for maps similar in quality to the Swedish maps. Further analyses will assess exposure modifiers, such as access to a quiet side of a building, which could be used to improve the precision of exposure assessments.

Conclusions, needs, challenges

The lack of accurate exposure data hinders an accurate estimation of the burden of disease due to environmental noise.

If L_{den} can be used in place of L_{day} , the noise-mapping data for the END can be used. Exposure data are, however, still sparse from WHO Eur-B and Eur-C subregions. Extrapolation of exposure data from the Eur-A to EUR-B and Eur-C countries might be problematic.

Noise levels under 55 dB L_{den} and 50 dB L_{night} are not reported and often not even estimated, but some people will still suffer annoyance. Given that the objective of the END is to “define a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to the exposure to environmental noise”, there is an argument for extending the scope down to $L_{den} > 45$ dB, as there is clear evidence that even at 42 dB there is a threshold for health effects (11). On the other hand, this will introduce large uncertainties into the calculated exposures. For the future it would be important to limit L_{den} and L_{night} values through EU guidelines.

The END allows for population exposure assessment at the individual level or at the level of individual buildings. There is a need for a common approach to assessing population exposure, if a comparative analysis of such exposure across EU countries is envisaged.

The quality of L_{den} and L_{night} maps can be expected to improve over time. Reasons for concern include:

- accuracy in linking people to noise levels and the resulting exposure distributions;
- coverage of all relevant noise sources, especially for 2007–2008, as one of the requirements in the first round of noise mapping in Europe;

- taking account of a quiet façade or special sound insulation, in particular for effects related to sleeping.

Recommendations from the ENNAH project

The following recommendations relating to future noise exposure assessment for health studies were also provided recently by the European Network on Noise and Health (ENNAH) project (12):

- concerns about the application of noise exposure data in health studies relate to details of the assessment (grid size, façade), assessment of low levels of noise and non-consideration of source spectral characteristics, which should, therefore, be addressed;
- individual noise exposure levels should be made available rather than 5 dB contours;
- in health studies, cut-off values should be introduced at the lower end (40 dB for road traffic, lower for air and rail traffic);
- assessments of the most exposed façades of buildings should be extended to other façades;
- accurate maps should be supplied (including for “dummies”); standardization is needed.

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10. Practical solutions for filling the gaps in (END) exposure data

*Erkki Kuusisto*²²

Introduction and aims

Strategic noise mapping provides valuable information on noise exposures in Europe, but the coverage and representativeness of the data are limited by its confinement to noise hot-spots. The exposure data mandated by the END are not, therefore, sufficient for nationwide health impact assessments. Further gaps stem from the non-coverage of low exposures and from the non-reporting of exposures to many relevant noise sources. Moreover, several European countries still lack resources for producing complete (or any) strategic noise maps. Thus, makeshift solutions are needed for overcoming the data shortages.

This section aims to summarize the main gaps in current exposure data for nationwide health impact assessments, and to outline a preliminary set of practical solutions for filling these gaps, even in countries with no strategic noise maps.

Gaps in current exposure data for nationwide health impact assessments

Population beyond strategic noise mapping

The main shortage of END exposure data for nationwide health impact assessments arises from the limitation of strategic noise mapping to hot-spots defined by the minimum size criteria for major agglomerations and transport passageways (1). Since large groups of the population live in areas where strategic mapping does not take place, a substantial proportion of all the people exposed to health-relevant noise levels will be missed. The exposure distributions obtained are not, therefore, representative of national populations in view of their bias towards relatively noisy areas.

Low exposure levels

The END does not require levels below 55 dB L_{den} or 50 dB L_{night} to be reported. However, when assessing annoyance and sleep disturbance, the most reliable exposure-response functions at present predict that some people are affected at levels down to 45 dB L_{den} and 40 dB L_{night} (2,3). While the reliability of the exposure-response functions in this regime is debatable, exposure prevalences are high in the low-exposure categories. Ignoring them may thus result in a substantial underestimation of the numbers affected.

Other health-relevant noise sources

There is a growing list of noise sources which fall into the scope of the END and may have a substantial health impact, but for which exposure reporting to the European Commission is not required. Among others, these include construction work, real-estate maintenance, outdoor entertainment, noisy leisure driving and wind farms. Noise from neighbours (including pets) and noise from military aviation are also relevant for health impact assessments, while outside the

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scope of the END. Many of the noise source mentioned are commonly perceived as annoying (4,5).

Night-time exposures and diversity of descriptors

It may be necessary to use non-END exposure datasets in place of or to supplement END data. However, a common limitation of non-END datasets is the paucity of night-time data. Moreover, many older exposure datasets used noise-level descriptors other than those employed in common exposure-response functions (for example, $L_{Aeq,24h}$).

Possible solutions for filling the gaps

The solutions proposed below are not designed to be ready-made tools, but rather crude outline methods to be further tailored for particular needs.

Populations beyond strategic noise mapping

To fill the primary data gap of END, that is, exposures in minor agglomerations, a generalizing approach based on sample (surrogate) populations can be used. The idea is to employ exposure data from a sample of cities/towns for which representative data can be obtained from, for example, existing noise maps or by ad hoc modelling (6). A set of representative cities/towns in different size brackets is identified and the average exposure distribution (the percentage exposed per each dB category) is then determined for each size bracket. These distributions are then generalized to all similar-sized agglomerations in the country.

Naturally, this approach can also be employed when no domestic END data are available. In such cases, it may be necessary to use exposure data from abroad. For example, to approximate the exposure distribution of large cities in the country, acoustically similar cities can be identified from the NOISE database (7) and their average exposure distribution compiled. These surrogate distributions may need to be adjusted on the basis of relevant variables and/or by expert judgement, the better to reflect the acoustic conditions in the country.

For minor roads, the generalizing approach can also be used, but instead of agglomerations a sample of representative road districts are chosen. For example, exposure distributions from districts already assessed for noise in other countries could be used and then generalized to all acoustically similar districts in the country. Exposures to major roads (as defined by the END) are then added, with appropriate measures to preclude double-counting. For minor railways, an analogous approach can be applied. For minor airports, the method proposed for agglomerations can be adapted.

Low exposure levels

Whenever feasible, the best remedy to obtain exposure data below 55 dB L_{den} or 50 dB L_{night} is to buy or request it from the agency or company that commissioned or implemented the noise mapping. This naturally requires that the mapping also covered low-exposure areas.

A secondary option is to use a fast but crude method, in which a flat distribution is assumed between 45 dB and 60 dB L_{den} (and between 40 dB and 55 dB L_{night}). That is, as a very first approximation, the exposure prevalences in the low-noise categories are assumed equal to those in the lowest reported categories (8). Depending on the type of source and target context, this rough method will produce an under- or overestimate, based on the examination of the exposure

distributions modelled for individual cities (5,9,10). However, it can be argued that ignoring the low-noise categories altogether probably results in a much larger error (in both numbers exposed and cases affected). Naturally the sum of exposure prevalences must not exceed 100%.

Other health-relevant noise sources

To assess the impact of other noise sources, an exposure-based approach is usually unfeasible due to the paucity/lack of exposure data and reliable exposure-response functions. For these sources, an outcome-based approach can be used if sufficient survey data are available. The data should indicate the percentage affected (by a particular outcome to a defined degree) by noise from a given source. The data can originate from surveys addressing either the population of interest or other populations subject to acoustically similar conditions (11). For inter-study comparability, standardized questions and response scales such as those specified in ISO/TS 15666:2003 (12) are preferred.

Night-time exposures and diversity of descriptors

Night-time exposure distributions can be deduced fairly accurately from daytime or 24-hour distributions using conversion formulas, if the activity profile of the source is known. Conversion formulas can also be used to employ exposure datasets using descriptors other than those in common exposure-response functions. However, the formulae should take into account all relevant variables: source activity profile, averaging times, time-of-day penalties, assessment heights, and meteorological average differences between daytime and night-time (13). Default values can be used where local input data are not available.

Summary of steps

To fill the gaps in END exposure data, the most appropriate procedure depends on the expected accuracy and on the availability of complementary/surrogate data. However, the overall workflow will include the following steps.

1. Retrieve domestic END data (if any) from NOISE and check for data consistency.
2. Search for complementary/surrogate exposure data (referring to step 3) from domestic and/or acoustically similar foreign contexts.
3. As needed, choose/tailor the most feasible methods:
 - for approximating daytime exposures if no END data are available
 - for estimating exposures beyond major agglomerations and passageways
 - for filling in low-exposure categories
 - for predicting night exposures, and
 - for descriptor conversions to comply with the exposure-response functions.
4. Process the exposure data to construct a nationwide dataset.
5. Calculate the health effects using the exposure-response functions.
6. To assess the numbers affected by other noise sources, use survey data from the population of interest or from acoustically similar populations.
7. Calculate DALYs.

The introduction of several types of uncertainty and error is unavoidable when approximating the exposures (13, Appendix 4). It is, therefore, crucial to highlight the main sources of potential error and to analyse their possible impact in order to avoid drawing scientifically ungrounded conclusions from the results.

Conclusions

The main gaps in END exposure data for health impact assessments are the non-coverage of populations beyond noise hot-spots, low-exposure categories and health-relevant noise sources not required for EC reporting. To augment the exposure data, many practical solutions of varying complexity can be adopted, even when no domestic END data are available. In addition, survey data can be used to assess the effects of many types of noise directly.

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11. Conclusions

Environmental noise is a threat to public health and well-being. Already, the outcome of the first round of strategic noise mapping suggests that at least 40 million people across the EU are exposed to night noise above 50 dB from roads within agglomerations. More than 25 million people are exposed to noise at the same level from major roads outside agglomerations. Common mitigation actions on the international, national and local levels are urgently needed. Reducing the exposure to noise generated by environmental sources in communities can only happen if public health policies are based on reliable evidence-based quantitative risk assessment methods.

Urban noise (mainly from transportation) causes annoyance, disturbs sleep, affects the learning and memory of schoolchildren, elicits physiological stress reactions and can lead to cardiovascular problems in chronically noise-exposed subjects. Adverse effects occur, in particular, when noise interferes with activities such as communication, concentration and sleep.

The EBoDE project applied a general methodology for the comprehensive assessment of environmental burden of disease, including the effects of noise exposure using data from the first round of strategic mapping. The primary metric in this methodology was the DALY.

To date there is sufficient evidence of adverse effects from exposure to noise for at least two health endpoints: IHD, with an emphasis on MI, as an objective outcome, and HSD as a subjective (self-reported) outcome.

Mathematical formulae describing the noise exposure-response for cardiovascular endpoints, annoyance and sleep disturbance have been developed to enable the quantitative assessment of the adverse effects of exposure, especially from transportation noise.

Step-by-step guidance for calculating DALYs due to noise exposure has been developed. This guidance defines the consecutive steps to be taken when evaluating the burden of cardiovascular disease and sleep disturbance related to environmental noise, using exposure data from strategic noise mapping. These steps follow the rules of good practice in EBD calculation, employing information about substantial health outcomes, exposure levels of the population, the most reliable exposure-response relations and baseline health data.

The END (Annex III) advises the use of exposure-response functions to assess the effects of noise on populations. The results of strategic noise mapping in accordance with the END serve as partial yet highly useful exposure data to be fed into the assessment process for the burden of disease from environmental noise.

Where END exposure data are incomplete or lacking (such as in south-eastern European countries and the newly independent states), a set of rough makeshift methods for generating approximate exposure data can be used to fill the gaps in coverage.

When the DALY concept is applied, the fundamental uncertainties affecting each step in its calculation must be borne in mind. Because of these uncertainties, both case number estimations and DALY calculation results must be interpreted with caution. This is of particular importance when the results are communicated to stakeholders and policy-makers and disseminated to the public.

This methodological guidance for estimating the burden of disease from environmental noise was launched by WHO-ECEH in order to provide evidence-based support to national and local policy-makers in risk assessment and management related to environmental noise. This guidance complements the existing portfolio of support materials such as the *Night noise guidelines for Europe (1)*, *Burden of disease from environmental noise: quantification of healthy life years lost in Europe (2)* and the *Good practice guide on noise exposure and potential health effects (3)*.

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12. The way forward

To protect public health from environmental noise, collaboration between WHO, EEA and the European Commission's Joint Research Centre and the Directorate-General for the Environment is being increasingly strengthened with the aim of implementing, in a synergistic way, the 2010 Parma Declaration (1) and the EU noise-related directives.

An important prerequisite for reliably applying the guidance for estimating the burden of disease from environmental noise is capacity-building and adequate training for EU member states, with a special focus on the south-eastern European countries and the newly independent states. As the task of reliably performing EBD estimations is tightly linked to the availability and quality of noise exposure data (mainly becoming available via the rounds of strategic noise mapping foreseen by the END), in late 2010 the above organizations formally agreed to align their noise-related activities and anchor them under the umbrella of the CNOSSOS-EU framework (1).

CNOSSOS-EU will allow for a coherent, transparent, optimized and reliable use of strategic noise mapping (first level of application, mandatory) and action planning (second level of application, voluntary) in relation to the data requirements, their quality and availability and, last but not least, in terms of flexibility to adapt the national databases of input values, thus ensuring a smooth transition from existing national methods to common methods. The CNOSSOS-EU tasks relevant to the estimates of the burden of disease from environmental noise are the following:

- task No.6: preparation of good practice guidelines on the competent use of the common noise assessment methods;
- task No.9: updating and enforcing the use of the EEA's data reporting mechanism;
- task No.11: WHO-ECEH's burden of disease estimation;
- task No.13: training of EU member states in effective use of CNOSSOS-EU.

The following activities are planned for the near future.

1. Extend the CNOSSOS-EU good practice guidelines to provide guidance on planning and performing calculations of the burden of disease from environmental noise on the basis of the step-by-step guidance for DALY calculation, using strategic noise maps (Chapter 6).
2. Develop a web-based tool for performing online calculations of the burden of disease from environmental noise via a standardized framework capable of:
 - coping with various health endpoints (3);
 - accommodating existing (pre-built) and new (customised) exposure-response functions for various noise sources and across specific noise levels;
 - choosing among a range of disability weights per health endpoint;
 - providing guidance on aggregating exposure data from country-specific strategic noise maps;
 - integrating to the burden of disease calculations report notions about quantitative/qualitative evaluation of associated uncertainties;
 - using the tool for training purposes.

3. Carry out joint EC-EEA-WHO training courses on the effective use of the overall CNOSSOS-EU framework for preparing strategic noise maps and action plans which include health risk assessments and estimations of burden of disease from environmental noise.
4. Perform a pan-European risk assessment of environmental noise, including economic evaluation.

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Methodological guidance for estimating the burden of disease from environmental noise

The World Health Organization, supported by the European Commission's Joint Research Centre, is issuing this technical document as guidance for national and local authorities in risk assessment and environmental health planning related to environmental noise. The principles of quantitative assessment of the burden of disease from environmental noise, the status of implementation of the European Noise Directive, and lessons from the project on Environmental Burden of Disease in the European countries (EBoDE) are summarized, together with a review of evidence on exposure-response relationships between noise and cardiovascular diseases. Step-by-step guidance is presented on how to calculate the burden of cardiovascular diseases and sleep disturbance. The limitations and uncertainties of estimating disability-adjusted life years and the usefulness and limitations of noise map data are discussed.

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