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European Network of the Heads of Environment Protection Agencies (EPA Network)

Decision and cost/benefit methods for noise abatement measures in Europe

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Summary

Traffic noise from road, rail and aircraft has a serious impact on public health. Increased health risks and annoyance lead to a lower state of wellbeing. Many noise abatement measures exist that decrease noise levels and protect the people from these negative impacts of transport. But noise abatement measures need to be paid for. And the budget for the noise abatement measures usually comes from national or local government. For serious noise related health hazards, cost considerations may not be relevant. But often, governmental administrations need to decide whether the costs for a noise abatement measure are justified by the benefits. Noise abatement, therefore, is a balance between the costs for prevention and reduction of noise and the benefits of lower environmental noise levels for society. It is the objective of this study to present the different approaches to the balancing and to identify the approach that is best fit-for-the-job.

Different decision methods used for noise abatement have been identified and compared:

- Cost Minimisation (CM),
- Cost Effectiveness Analysis (CEA),
- Cost Utility Analysis (CUA),
- Cost-Benefit Analysis (CBA) And
- Multi Decision Criteria Analysis (MCDA).

Costs are always a criterion, in each of these methods. The methods differ in the way the benefits are quantified. Benefits may be quantified in terms of public health units (DALY), as is done in CUA, or just in terms of noise reduction in dB or dB * persons (CEA), or may not be quantified at all (CM). CBA and MCDA are both able to perform a more integral consideration of multiple different criteria: costs, annoyance, health, but also safety or social security issues, aesthetic and socio-cultural criteria, for instance. MCDA is more suitable for the local project scale, whereas CBA is the most common option for policy making on the national or international scale.

The main characteristic of CBA is that both the cost and benefit sides are expressed in money, allowing a direct comparison between costs and benefits. The strong advantage of CBA is that it allows to set an absolute level for the budget that should be made available for noise abatement (whereas the other methods are only able to compare one alternative to another). This requires, however, that all benefits for environmental aspects, such as noise, are translated to monetary units. This process of 'monetarisation' is difficult in itself. Common methods aim to establish the 'Willingness-To-Pay' (WTP) for a reduction of annoyance and sleep disturbance, with additional costs for long-term health impacts. The WTP may be established through stated preferences methods (public surveys) or through revealed preferences methods, such as hedonic pricing (investigating the relation between noise levels and real estate prices or rents). These methods have advantages and disadvantages, but a common problem with all methods is the limited accuracy of the result.

Experiences with decision making and application of cost/benefit methods in several European countries have been gathered and analysed using an online survey through the EIONET network. From the current practice of decision making, we find that:

- <u>costs</u> are always an important criterion for noise abatement measures, but differences exist as to what is actually included in the costs (e.g. maintenance costs, passive noise measures);
- <u>benefits</u> are usually expressed in the amount of noise reduction in dB, often combined with the number of people that benefit from the measure. Monetarisation is common, although rarely as part of national legislation. Values for WTP differ widely across different countries. Other units, such as DALY's are also used;
- <u>other</u> criteria, mainly safety/reliability issues, technical limitations and maintenance are also considered, as well as considerations on the impact on the visual landscape, or socio-cultural

appropriateness. These decisions, however, are rarely integrated in the decision making process or method.

We find large differences in the levels or stages at which these cost/benefit decision methods are implemented in national legislation. This varies from sophisticated and well-defined cost/benefit calculations and effectiveness judgments, which may or may not have legal status, to areas without any common approach to cost/benefit decisions, leaving them up to the project engineers and local authorities on an ad-hoc basis.

The extent of noise abatement measure also differ largely between countries. For countries that are able to spend money on noise abatement measures often, a well-defined system for decision making is more important to guarantee an equal and fair distribution of the available budget over projects and problem areas. Countries with small budgets focus on the most extreme cases only and often need no additional method to identify or rank these. The END noise action plans are a common starting point for noise abatement policy decisions.

For policy makers looking to introduce or to improve their decision making methods for noise abatement measures, we summarize the following recommendations:

- A well-defined and described decision making method, including prescribed cost/benefit calculations, is recommended to enable fair and transparent decisions.
- It is recommended that policy makers do not invent their own, new methods, but look to other European countries for best practice. Best practice guidelines may also be provided on a European level, perhaps by the EPA Network.
- A good method should include:
  - a clear and complete definition of costs;
  - a well-defined quantity for the benefits, that includes annoyance, sleep disturbance and related health effects. Monetary values, if used, and their uncertainties, should be clearly reported;
  - considerations for other criteria should be included in the decision making method, or at least be specifically included in the decision process, at an appropriate time;
- For the evaluation of cost effectiveness, noise limits are not required, but they may help selecting the cases where cost considerations are applicable. On the opposite side, however: in a system with noise limits, there is definitely a need for cost-benefit evaluation to avoid very high costs for limited extra benefits

Based on our investigations into existing methods, we give the following recommendations for choosing a decision method for traffic noise abatement measures:

- For simple projects with clear boundaries, simple cost/benefit methods may be sufficient. We do recommend to look not only at cost minimisation, but also at cost effectiveness by regarding the extra noise reduction vs. the extra costs of various abatement measures.
- For these specific projects, we recommend to consider MCDA as an alternative to CBA, in order to include other aspects, such as aesthetics, socio-cultural and social security aspects, and also to increase public involvement and awareness.
- For national policy development, we recommend CBA, since this is the only method that enables the establishment of an absolute level for the budget that is available for noise abatement measures. CBA requires monetarisation of health and annoyance costs. These values may be obtained either by hedonic pricing or by stated preferences methods, as long as the WTP values used are clearly defined. Uncertainties in these values should be clearly reported and considered when drawing conclusions.

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Abbreviations

BPR	bypass ratio (of aircraft engines)
C/B	cost/benefit
CA	conjoint analysis
CAEP	Committee on Aviation Environmental Protection
CBA	cost-benefit analysis
CBI	cost benefit index
CE	choice experiments
CEA	cost effectivity analysis
CEDR	Conference of European Directors of Roads
CI	cast iron (braking blocks for rail vehicles)
CM	cost minimisation
CUA	cost-utility analysis
CV	contingent valuation
DALY	disability adjusted lifetime years
dB	decibel
dB(A)	A-weighted decibel
DNL	day-night average sound level
DPSIR	drivers-pressure-state-impact-response
DW	disability weight
EC	European Commission
EEA	European Environmental Agency
END	environmental noise directive
EPA	environmental protection agency
ETC	European topic centre
EU	European Union
HEATCO project	Developing Harmonised European Approaches for Transport Costing and Project Assessment
hh	household
HOSANNA project	HOlistic and Sustainable Abatement of Noise by optimised combinations of Natural and Artificial means
HP	hedonic pricing
IGNA	interest group on traffic noise abatement
IPA	impact pathway approach
$L_{A,eq}$	A-weighted time-averaged equivalent noise level
LCC	lifecycle costs
L_{den}	yearly averaged day-evening-night noise level
L_{eq}	time-averaged equivalent noise level
L_{max}	maximum noise level
L_{night}	yearly averaged night-time noise level
MDCA	multi-design criteria analysis
NAP	noise abatement procedures (for aircraft take-off/landing)
NDI	noise depreciation index
NDSI	noise depreciation sensitivity index
NDTAC	noise-differentiated track access charges

NFP	national focal points
NOx	nitrogen oxide (NO and/or NO2)
NRA	national road authority
NRC	national reference centre
QALY	quality adjusted lifetime years
RIVM	Dutch Institute for Public Health and the Environment
RP	revealed preferences
SEL	sound exposure level
SP	stated preferences
STAIRRS project	Strategies and Tools to Assess and Implement noise Reducing measures for Railway Systems (project)
UNITE project	UNIfication of accounts and marginal costs for Transport Efficiency
VOLY	value of a statistical life year
VSL	value of a statistical life
WG-HSEA	EU Working Group on Health and Socio-Economic Affairs
WHO	World Health Organisation
WTA	willingness to accept
WTI	Wirtschaftlichen Tragbarheitsindex
WTP	willingness to pay

1 Introduction

1.1 Aim of IGNA

The EPA Network is an informal group bringing together the heads of environment protection agencies and similar bodies across Europe. The network exchanges views and experiences on issues of common interest to organisations involved in the practical day-to-day implementation of environmental policy.

In the September 2010 EPA-Network meeting in Krakow an Interest Group on Traffic Noise Abatement (IGNA) was created. The IGNA is a forum to exchange information on current and future developments, an opportunity to learn from each other, particularly in relation to the development of the regulatory framework and scientific issues. Generally, the group's outcome are reports on the activities of the group, containing concrete and helpful recommendations to successfully protect the population from traffic noise.

The Swiss Federal Office for the Environment has contracted M+P -Consulting engineers in The Netherlands to support the IGNA with relevant input for the work of the IGNA, with the preparation and reporting of the IGNA workshops, with summarizing the discussions within the workshops and with the composition of a final report [1].

A very relevant topic that the IGNA focusses on are decision methods for noise abatement measures in Europe. As most of the countries use economic cost-benefit methods as well as public health or other criteria in their decision-making to enforce an action plan of noise abatement measure, it is of great interest to evaluate how nations or regional authorities define the optimal noise abatement approaches in order to find a common approach in Europe.

1.2 Objective and approach in this study

The objective of this study is to distinguish, describe and compare the different methods for cost optimisation of decision-making for noise-abatement measures. Also, the study aims to gain insight in which methods are actually used in practice on local, national and European scales. The authors of this report hope to contribute to the exchange of knowledge and experiences in different countries, which will lead to a more successful implementation of noise abatement measures in Europe and a further reduction of the environmental noise problem.

The following tasks have been carried out in order to obtain an overview of methods that are usually applied:

- Analysis of Literature of the up-to-date decision methods (cost-effectiveness, cost-utility, cost-benefit, monetization methods for health criteria, external costs, etc.) for noise abatement measures
- Evaluation of some practical examples from European countries, from literature, but also by inquiring EPA members from several countries;
- Overview and discussion of methods (pros and cons), both from a theoretical point of view and from common practice;
- Recommendations of best practice method to be used in noise abatement.

1.3 Timeline

After the June 2015 IGNA meeting in Maastricht, it was decided to draft a separate report, focusing entirely on cost/benefit analysis, decision making methods and economic aspects of environmental noise. The work for this project has been done according to the following timeline:

- September 2015: start of work;
- June 2016: presentation of first draft version at the 8th IGNA meeting in Bern;
- June – October 2016: online EIONET survey regarding decision methods and cost/benefit;
- August 2016: presentation of intermediate results at Internoise in Hamburg [5];
- September 2016: presentation of intermediate results at EIONET Noise Workshop in Copenhagen;
- January 2017: final draft version of the report, with processed comments from IGNA members;
- June 2017: presentation of final draft version, as a summary of best practices, at ICBEN in Zürich [6].

Also, the authors attended the CEDR Symposium on road traffic noise management and abatement, to compare and discuss our findings on cost benefit and decisions with CEDR research [24].

1.4 Costs and benefits

Noise abatement is often a balance between the costs for prevention and reduction of noise and the benefits of lower environmental noise levels for society, such as less health impacts and other less external costs. One could add up the costs of the measures and the costs of the remaining noise problem. A higher level of environmental protection will lead to higher costs of noise abatement measures, but not necessarily to higher total costs, as the external costs are considered in the balance. However, removing all unwanted noise from environment to background noise levels would imply very drastic measures the costs of which will not be balanced by the costs saving at the impact side (expressed for instance by the willingness to pay for it by society). On the other hand, a low protection level implies low direct costs for noise abatement, but will cause significant costs at the impact side due to the level of nuisance and health related impacts.

The balance between costs and benefits can be based on:

1. Monetary balance: costs related to the noise abatement should be equal to, or should be considered acceptable with respect to, the “external costs”;

2. Predefined accepted health and nuisance risks, set by local, national or international environmental policy and legislation.

figure 1 The costs of noise abatement are balanced with the benefits for society

The balance can be defined per project or on national/international scale or on the type of infrastructure.

- Balancing per project will cause inequalities between level of protection, which may not be accepted by the people concerned.

- Balancing on a national/international scale requires generalization and averaging, which can lead to under performance in one project (limited extra costs for noise abatement would lead to a much greater effect) and over performance at another (the costs of noise abatement measures exceed the desired effect). In general, a well-done balancing leads to good results.

- Some noise measures can only be applied on a national or even international scale: vehicles measures, such as low-noise road vehicles and tyres, or retrofitting of braking systems on international train wagons, must be taken on a European level.

In practice, hybrid forms are common: national based limit values with local cost/benefit balancing. Also, the balance between costs and benefits are, in most examples from practice, only part of the decision making: other criteria, that are not part of the cost/benefit analysis, have an important influence. Cost/benefit analysis methods may, in principle, be used to incorporate all of these criteria, but they require that both the costs for noise abatement measures and all criteria on the benefit side can be expressed in monetary units ('monetarisation'). Monetarisation is not always possible or accurate, and is not always necessary. Within the family of 'cost/benefit analysis' methods, other methods exist that compare the costs directly to the noise reduction or the health impact. Multi-decision criteria methods also enable the incorporation of non-monetary benefits and may be a good alternative for specific situations.

An important question is who actually pays for the external costs: in most cases, the traffic user (the polluter) does not directly compensate for the impact he/she causes; instead, the noise abatement measures are financed by the government, with tax money that comes from the whole society. Governments and administrations are searching how to implement the 'polluter pays' principle; see section 4.2 on internalisation of external costs.

2 Impact of traffic noise

2.1 Introduction

To approach the problem of traffic noise, we use the DPSIR framework introduced by the European Environmental Agency (EEA). DPSIR indicates the Drivers-Pressure-State-Impact-Responses system in which the fundamental causes, the environmental pollutants and its effects and the reaction of society and legislation to control the adverse effects are fitted in a general framework. Application of this framework on different environmental issues leads to a better understanding of the underlying relations and components common to different environmental issues.

More details on the DPSIR system and the different components for traffic noise are given in a related IGNA report [1]. In the current report, we look mainly at Impact and Responses (as the red circle in figure 2 indicates).

The present chapter addresses the *impact* of traffic noise on the population. In the following chapters the *response* will be described, not so much as in technical terms but in financial terms and as decision process. Issues such as “How to determine if the impact is severe enough to respond?” or “Which noise abatement measures are considered and how much budget should be made available?”.

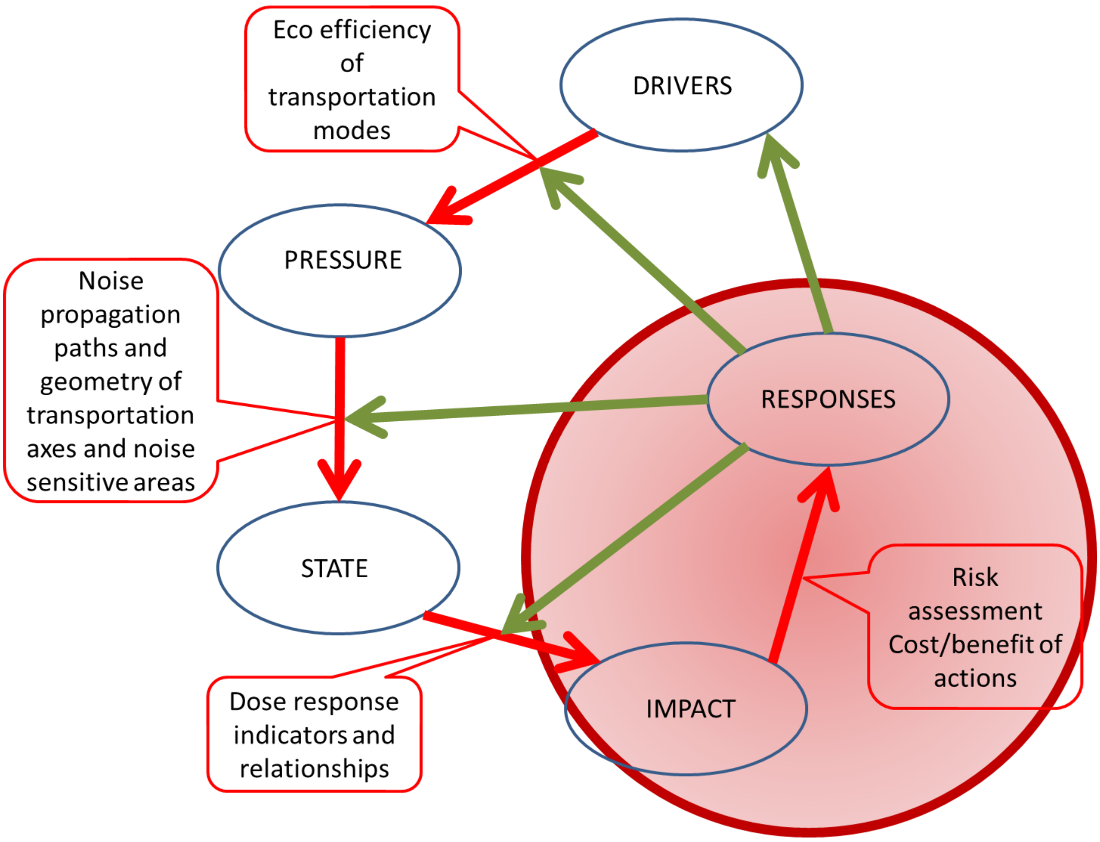

figure 2 *Scheme of the DPSIR framework with noise related issues. The red circle indicate the topic area of this report.*

table I *DPSIR framework components for traffic noise*

Drivers	growth of transportation due to economic development, work and settlement patterns, production and trade patterns, leisure patterns
Pressures	The production of sound from the vehicles used for transportation (other to transport related sources, such as workshops, power stations etc. are neglected)
State	transportation noise assessment, exposed population, exposed land area, measures Lden, Lmax, Lnight, quiet areas
Impact	effects of transport noise on the population in terms of health, annoyance and sleep disturbance. In addition negative effects on fauna can be taken into account.
Responses	Responses from mainly supra national, national or local administrations. E.g. tightening of certification noise limits, taxation or curfew of noisy crafts, both road, rail and air (NDTAC, Night ban, CI-ban,…), regulation of transport (vehicle speed, aircraft and rail routing), infrastructure (low noise pavement, noise barriers, rail dampers, rail grinding,..), planning (separation of noise producing and noise sensitive areas), public awareness,

2.2 Impact of traffic noise on health and annoyance

2.2.1 Definitions

Health
Several different definitions of *health* exist. The World Health Organisation (WHO) gives some examples in their 2010 Good practice guide ([7], Annex I). In most literature found on the health implications of environmental noise, the definition used is from WHO in 1946:

> ***Health*** *is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.*

Compared to others, this is a rather broad definition of health, which includes the entire range of severity from mortality and cardiovascular diseases down to increased stress and disturbance or annoyance.

Annoyance
In several literature sources, especially the literature covering benefits of noise reduction or reduction of external costs, for instance the EC handbook on external transport costs [11], a separation is made between *health* effects and *annoyance*. The *annoyance* is defined in the EC handbook as “reflecting the disturbance which individuals experience when exposed to (traffic) noise”. When this separate definition of annoyance is used, the definition of health is different, e.g. more narrow, than stated above, since disturbance or annoyance, and possibly also ‘stress’, are not included. Annoyance may be expressed in quantitative ranges: ‘not annoyed’ – ‘slightly annoyed’ – … – ‘extremely annoyed’.

Environmental noise
The WHO defines *environmental noise* as follows:

> ***Community noise*** *(also called* ***environmental noise****, residential noise or domestic noise) is defined as noise emitted from all sources, except noise at the industrial workplace. Main sources of community noise include road, rail and air traffic, industries, construction and public work, and the neighbourhood.*

The Environmental Noise Directive (END) of 2002 considers *environmental noise* as being:

> *unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic and from sites of industrial activity.*

The END definition is more narrow, since it does not include noise produced by the people themselves (domestic activities, neighbours, etc.). These topics are considered to be addressed by other legislation or policy instruments.

This report focusses on noise abatement measures for traffic noise, from road, rail and air traffic. Other components of environmental noise have an influence on public health, but we do not include the other components in our description of decision making criteria, costs/benefits and decision methods.

2.2.2 Health endpoints

The effects of environmental noise on health have been widely studied over the last decades, and the research world is still actively working on the subject. The WHO has provided a comprehensive overview of the different health effects in 2011 [12]. The overview includes the exposure-response relationships found from a review of scientific evidence and case studies performed by the WHO working group.

Significant negative impacts from environmental aspects have been found on the following health aspects:

- cardiovascular diseases: mainly ischaemic heart diseases and hypertension. Ischaemic heart diseases include angina pectoris, myocardial infarctions and subsequent complications, and other acute and chronic forms of ischaemic heart disease. Hypertension (high blood pressure) may lead to hypertensive heart failure and renal disease (kidney failure). Cardiovascular disease also includes stroke, but no evidence on the direct relationship between noise and stroke was found.
  The main biological cause for the relation between cardiovascular diseases and noise is the increased nonspecific stress that humans experience when exposed to high noise levels for a longer period of time.
- cognitive impairment in children: the negative impact on children's learning ability and memory. The WHO 2011 report defines the noise related cognitive impairment as "*reduction in cognitive ability in school-age children that occurs while the noise exposure persists and will persist for some time after the cessation of the noise exposure*". Some studies have shown that the effects of noise on cognition may be reversible if exposure ceases, after some time (up to two years). Exposure during critical periods of learning at school could however impair development and have a lifelong effect on educational attainment.
- sleep disturbance: acute and chronic sleep restriction, i.e. the inability to sleep for some period of the night, or sleep fragmentation due to repeatedly occurring activations of the body and brain, which reduces the restorative power of sleep. Noise may increase the wake time of the human subject, but may also influence the various sleep stages (superficial vs. deep sleep and REM sleep stages). Sleep disturbance has been shown to have effects during wake time on psychomotor performance, memory consolidation, creativity, risk-taking behaviour, signal detection performance and risks of accidents.
- tinnitus: tinnitus is the general term for perception of sound (e.g. roaring, hissing or ringing) that cannot be attributed to an external sound source. It may also be defined as the inability to perceive silence. There is a wide variation of the severity of tinnitus. Nearly everyone suffers some mild, occasional or acute temporary tinnitus at some time or another, usually resolving spontaneously. Some people, however, experience a constant disturbance of their emotional, cognitive, psychological or physical state, which causes an impact on his or her functional life. Tinnitus caused by excessive exposure to noise has been long described. The majority of patients with chronic noise trauma report tinnitus.

Many people with noise-induced hearing loss report also tinnitus, but tinnitus may also be experienced with people exposed to excessive noise who do not have measurable hearing loss. Hearing loss as such is not expected to occur at L_{Aeq} levels of 75 dB(A).

- annoyance: annoyance contains a variety of negative responses such as anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation or exhaustion. Furthermore, stress-related psychosocial symptoms such as tiredness, stomach discomfort and stress have been found to be associated with noise exposure and noise annoyance. As stated earlier, not all studies consider annoyance to be a negative health impact, since it does not (significantly) contribute to disability and is not a 'disease'. In the wider definition of health adopted by the WHO, annoyance *is* included and clearly related to environmental noise.

The WHO is currently working on an update of their guidelines for environmental noise. Their conclusions will be based on objective assessment and reviews of available international studies on noise and health. Their final results are expected to be presented in 2018. Intermediate results have been presented at Internoise 2016 in Hamburg, at the EIONET Noise Workshop 2016 in Copenhagen and at the ICBEN2017 conference in Zürich. New research indicates that in addition to the health endpoints above, significant correlation with noise, as well as a biological chain-of-cause, have been found for obesity, diabetes and some forms of breast cancer.

2.2.3 Threshold values

In table II below, the different effects of environmental noise on health are summarized. For each health end-point, an acoustic indicator and a threshold value in dB are given. It is clear that sleep disturbance (42 dB L_{night} or 32 dB L_{max} indoors) and annoyance (42 dB L_{den}) occur at quite low levels, whereas the chance for ischaemic heart diseases is only affected by noise levels over 60 dB L_{den}.

Threshold values have also been studied more recently by RIVM and others [13]. They indicate that a certain risk of increased annoyance and sleep disturbance is also present at lower levels than 42 dB L_{den}/L_{night}. They also indicate that an increased risk of coronary heart diseases and stroke occurs at lower levels, starting from 50 dB L_{den}.

table II *Effects of noise on health and wellbeing with sufficient evidence (from [1] [7])*

effect	dimension	acoustic indicator[1]	threshold[2]	time domain
annoyance, disturbance	psychosocial, quality of life	L_{den}	42	chronic
self-reported sleep disturbance	quality of life, somatic health	L_{night}	42	chronic
learning, memory	performance	L_{eq}	50	acute, chronic
stress hormones	stress indicator	L_{max} L_{eq}	NA	acute, chronic
sleep (polysomnographic)	arousal, motility, sleep quality	$L_{max,\ indoors}$	32	acute, chronic
reported awakening	sleep	$SEL_{indoors}$	53	acute
reported health	wellbeing clinical health	L_{den}	50	chronic

[1] L_{den} and L_{night} are defined as outdoor exposure levels. L_{max} may be either internal or external as indicated

[2] Level above which effects start to occur or start to rise above background

effect	dimension	acoustic indicator[1]	threshold[2]	time domain
hypertension	physiology somatic health	L_{den}	50	chronic
ischaemic heart diseases	clinical health	L_{den}	60	chronic

2.3 Overall impact on EU population

An attempt to map the full impact of traffic noise on the EEA 33 population was performed by RIVM for the EEA in 2015 [13]. RIVM has estimated the total impact by gap-filling the results for the data that had not (yet) been reported.

Also, the study extended the noise exposure range beyond the lower limits set in the END (to L_{den} levels below 55 dB and L_{night} levels below 50 dB) where, especially in the case of aircraft noise, still significant annoyance and sleep disturbance occurs. The updated estimation for the impact off road noise, including these lower noise levels as well as the gap-filling, is about 2.5 to 3 times higher for (severe) annoyance and about 3.5 times higher for (high) sleep disturbance, compared to the noise mapping data. The estimated overall effects are presented below (see figure 3).

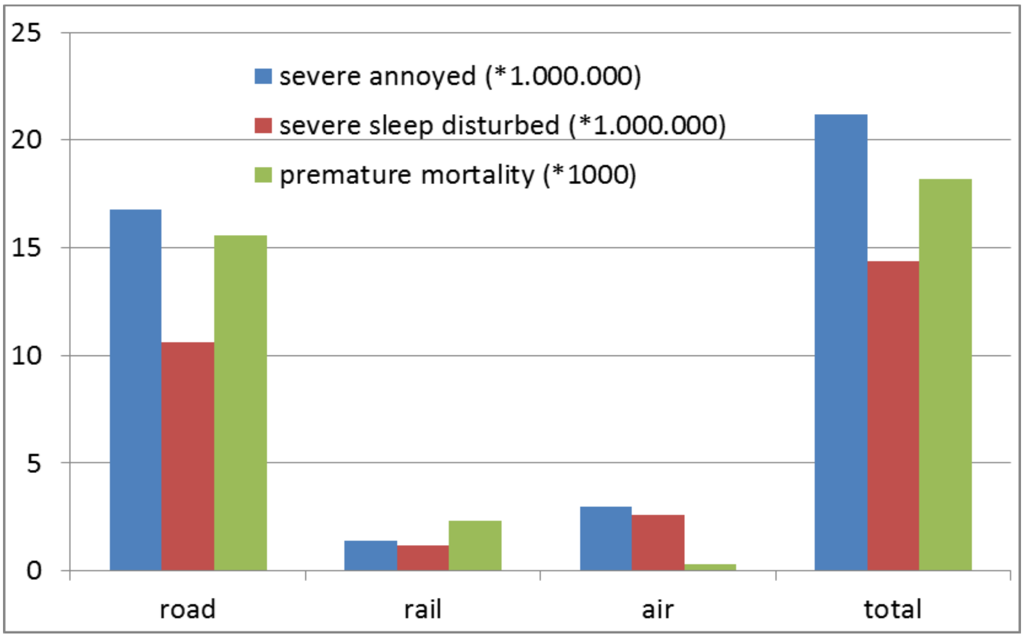

figure 3 *Impact of traffic noise on the European population. Estimates of number of people affected in the EU27 based on extrapolation to 100% coverage and on including estimated impacts below reporting values of L_{den} 55 en L_{night} 50 dB*

3 Costs of noise abatement measures

3.1 Introduction

The application of a noise abatement measure, in general, costs money. Noise reducing pavements are more expensive than the standard surface, at least when evaluated over a long period. Noise barriers are quite expensive to build and maintain. Most noise measures on vehicles (aircraft, rail or road) lead to higher production costs and therefore a higher price. Examples of cost-free noise abatement measures may exist, but they are rare. Lowering the maximum allowed vehicle speed could be considered a more or less cost-free investment, apart from a few extra speed signs, but only if the time loss of traveling is not taken into account.

In the total amount of money that needs to be spent on a particular noise abatement measure, one distinguishes:

- direct costs:
  - investment costs for instalment of application of the noise measure, e.g. the construction costs for a noise barrier;
  - increased costs for maintenance and preservation of the noise measure, e.g.: higher maintenance costs and lower durability for porous road surfaces, or acoustic grinding to obtain and preserve a lower rail roughness;
- indirect costs:
  - high/lower operating costs, e.g. longer flying distances for noise-optimised take-off and approach routes.

3.2 Road traffic noise abatement measures

Road noise measures have been discussed in our earlier IGNA input paper for road traffic noise [2]. In figure 4 below, some cost values are given for different noise abatement measures, with the approximate noise reduction on the vertical axis. We can distinguish the following noise measures:

- traffic measures: lowering the vehicle speed by setting a lower speed limit. The noise reduction depends on the speed reduction, and is approximately 1 to 1,5 dB for a 10% decrease in vehicle speed. The direct costs of this measure are close to zero. The indirect financial costs may also be close to zero: lower driving speeds may actually save fuel and money. Travelling times, however, will increase, at least in non-congested situations. The time and productivity lost to travelling needs to be accounted for somehow (time is money). In our definition, the economic value of the increased traveling time is considered as a separate criterion (see 7.1.4).
- low-noise tyres: the noise reduction from low-noise tyres depends on vehicle speed and road surface type, but may be around 3 dB. Costs are low, because there seems to be virtually no correlation between the noise level and the price of the tyre [16]. The cost value in figure 4 is taken from RIVM [41].
- low-noise road surfaces: many types of low-noise surfaces exist. In figure 4, three types of porous road surfaces are indicated. Noise reductions are taken from Dutch legislation, for mixed traffic at highway speed. Cost values are LCC costs, investment plus 30 years of maintenance costs, for a 20 m wide road, taken from [15].
- noise barriers: the noise reductions in figure 4 have been calculated for mixed highway traffic, with a single reflective noise barrier 10 m from the centre of the outmost road lane. Cost values are LCC costs, investment plus 30 years of maintenance, taken from [15].

Measures to silence the vehicle itself (engine, exhaust / inlet, gearbox, etc.) are not included in this graph. These measures will only be effective at lower vehicle speed, mainly on urban roads, since tyre/road noise dominates the overall noise level at constant speeds from 35 km/h (cars) or 65 km/h (trucks) upwards. The introduction of hybrid and electric vehicles will further reduce the contribution of the propulsion system. At lower speeds, however, the vehicle noise is still a problem, and measures to silence the vehicle will be quite effective to reduce inner-city noise. Cost estimates, however, have not been found.

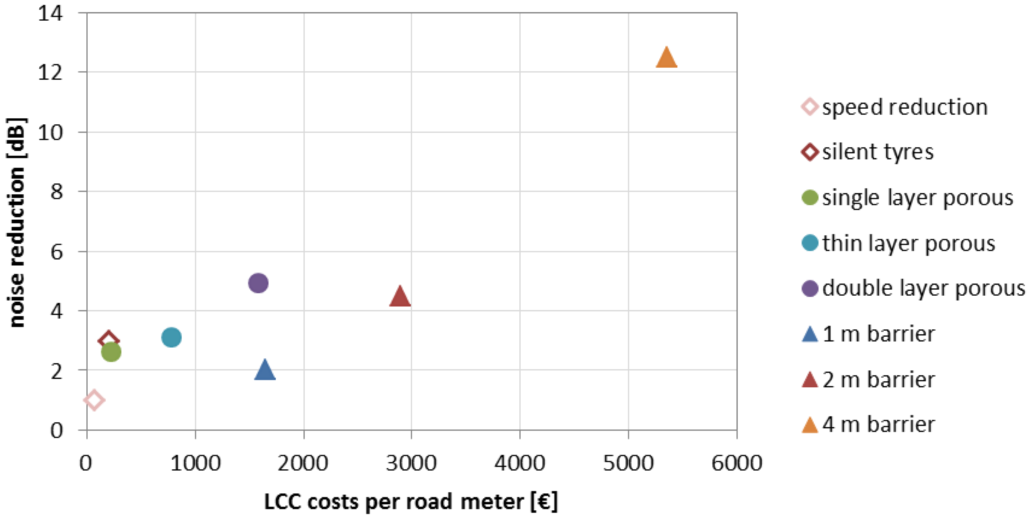

figure 4 *Noise reduction vs. costs per road meter for various source measures, porous road surfaces and noise barriers; noise reductions for a typical highway situation with mixed traffic (data from [15] and [41])*

3.3 Rail traffic noise abatement measures

Railway noise measures have been discussed in our earlier IGNA input paper for rail traffic noise [3]. In case of railway noise, four types of noise abatement measures are considered:

- vehicle measures:
  - retrofitting cast iron brake blocks with composite (K- and LL-type) blocks for freight wagons (vehicle measure)
- track measures:
  - acoustic grinding
  - tuned absorbers (or ‘rail dampers’)
- propagation measures:
  - noise barriers

For railway noise abatement measures, the STAIRRS project [17] compared the costs for these four different types of noise abatement measures, for 11.000 km of railway track in seven European countries. The result was used and updated with values for tuned absorbers and noise barriers in a project for the Dutch rail authority ProRail [20]. In figure 5, the LCC costs (direct costs for investment and maintenance) for 30 years are given over a period of 30 years for the track and propagation measured, expressed as a price per meter railway track. On the vertical axis, the noise reduction is given. In figure 6, the costs of K-blocks are also included, as well as some combinations of noise measures. The vertical axis now shows the decrease in noise exposure (people * years) above 60 dB(A).

Compared to figure 4, the costs for a 2 m barrier along a railway seem to be much lower than the costs for a similar barrier along a road, which is not reasonable. The values come from quite different sources, and behind it are different starting points regarding:

- VAT: included in the road estimate (19%) but not in the rail estimate;
- the price level year (2007 for the road estimate, 2004 for the rail estimate);
- the type of noise barriers included: the average estimate for rail includes the relatively cheap earth walls and gabions, whereas the road estimate does not.

These difference account for a factor 1.6 increase of the road estimate with respect to the rail estimate. The remaining difference lies primarily in the maintenance costs over 30 years (LCC), which have been estimated lower in the rail study than in the road study.

This example points out that calculating LCC costs is not straightforward and different methods may lead to quite different results, even if the *actual* prices are more or less equal.

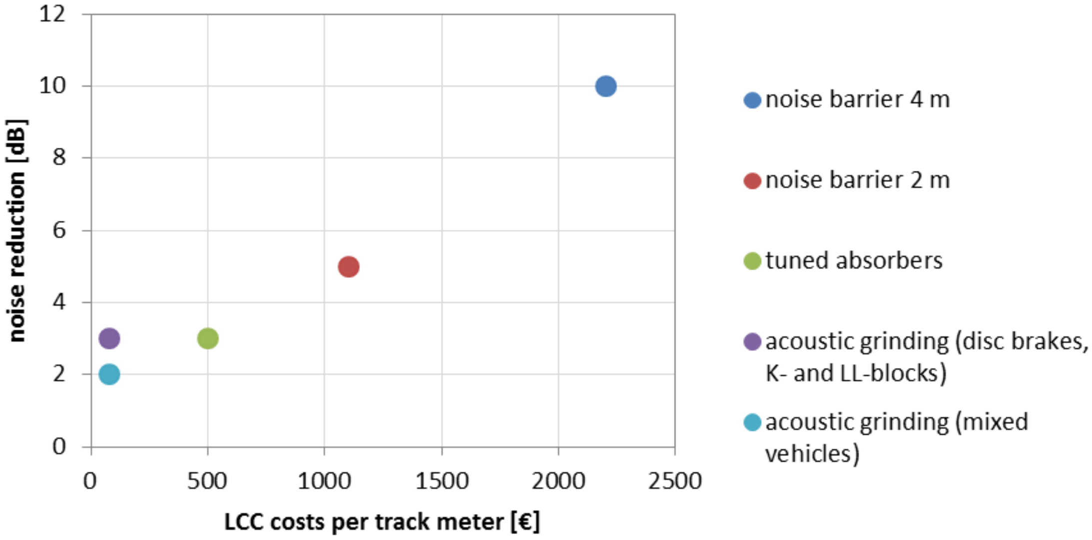

figure 5 *Noise reduction vs. costs per track meter for various track measures and noise barriers; costs are LCC costs over a period of 30 years; noise reductions based on Dutch legislation (adapted from [20])*

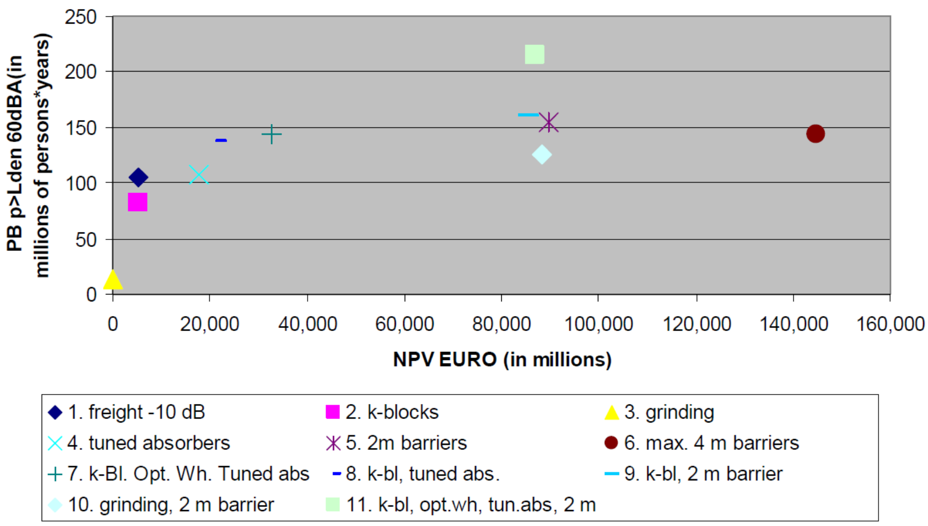

figure 6 *Costs of different rail noise abatement measures and benefits in terms of the reduction of people exposed to L_{den} > 60 dB(A) in EU27+Switzerland+Norway [8].*

3.4 Air traffic noise abatement measures

Aircraft noise measures have been discussed in our earlier IGNA input paper for air traffic noise [4].

The cost of noise mitigation measures are related to the costs involved in technical and operational measures:

1. Hush kitting of existing aircraft
2. Replacement by noise optimised types.
3. Extra flying distances caused by following noise optimised routes for landing and take–off paths.
4. Extra runways when runway capacity is reduced by noise abatement procedures.

3.4.1 Hush kitting

The costs of hush-kitting (adding silencing systems to the engine such as chevrons and liners) are estimated in a study given in [53] where for the OHARE airport near Chicago costs are estimated to reduce the emission of chapter 2 aircraft to marginally compliant chapter 3. It was found that over a 10 yr. period the costs of the installation and the extra costs due to lower fuel efficiency was estimated on an average 2,7 M$ per plane. Taking into account the number of operations on the airport of each plane, a cost of $ 700,- per operation was concluded. It must be noted though that practically all hush kitted aircraft are phased out nowadays.

3.4.2 Replacement

Partial or full replacement of the aircraft presents a cost factor due to the faster depreciation of the older aircraft, but it also presents a profit since newer aircraft vehicles save fuel and therefore costs. Taking into account the slope in aircraft noise levels versus manufacturing of about 0,2 dB/yr per type of operation, or 0,6 dB/yr cumulative over three operations, and assuming a service life of 25 years before its asset value is zero, it can be concluded that, as a generalized estimation, each 1 dB reduction (3 dB cumulative) presents retiring the old plane 5 years earlier related to a depreciation of 20% of the costs of the plane [4]. Examples also exist, however, of newer aircraft with other engine technology (e.g. open rotor) that are louder than an older conventional jet model with a high ByPassRatio.

The fuel efficiency associated with newer engines at the other hand will present a saving. Retiring a plane and replacing it with a new one at 20 years of age, instead of 25 years, presents an improvement in fuel efficiency of about 20%. The effect of this can be estimated as follows.

1. The average fuel consumption of a modern 200 seat plane is about 50 g/pax/km
2. The average distance travelled by an aircraft per year is about 1,5 M km.
3. The 2014 fuel price is 3$/gallon which is about € 0,80/kg.
4. A 200 seater thus uses 15 M kg jet fuel per year equals about 12 M€/ year as fuel costs.

A saving of 20% represents a saving of 2,4 M € per year which over the 5 year earlier retirement period presents a sum of 12,5 M €. This figure almost covers the costs of a 5 year earlier retirement of a 65 M € aircraft.
In basic economic terms early retirement carries no costs but represents an improvement for society because of the 1 dB lower noise level per operation. Also the improved NOx emission (CAEP stringency reduction of -50% over the last 20 years) will present a profit for society. It is the estimation of CAEP study group [49] on the C/B ratio of NOx stringency that the benefit of this effect supersedes the effect of noise considerably. However, in modern engines there exists a trade-off between CO_2 and NOx emission. Further modernization of an already modern fleet might lead to further fuel saving and less noise but the NOx emission might get worse.

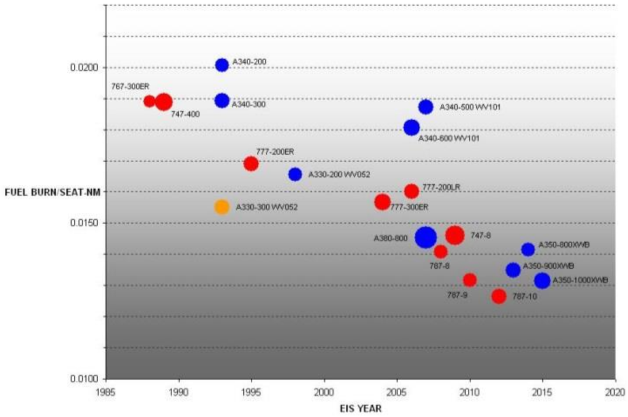

figure 7 *Development of fuel efficiency over the period 1985 -2015. Source: www.airliners.net*

3.4.3 Costs of extra distance and time loss

It is our estimation that this is a minor effect since it affects only the local routing and not the paths between the exit and entrance points at origin and destination airport. The latter represents the largest fraction of the travelled route.

3.4.4 Costs of extra infrastructure

This might be a significant effect when Noise Abatement Procedures (NAP's) are enforced in busy periods of the airport. At the moment, safety considerations prevent such NAP's in the busy periods. There are costs involved in building extra infrastructure to enable noise optimised routes. For instance, in Amsterdam Schiphol an extra runway was built to enable take-off and landing over a less populated area. The magnitude of such costs however is very hard to determine.
The infrastructure costs may also not be completely attributable to the environmental noise. Relocation of an entire airport because of noise alone is not likely to happen, but in the selection of a location for a new airport, a more expensive location may be favoured if the environmental impact, including noise, are lower.

Additional costs for changes in noise optimised routes may also come from additional navigation equipment (RNAV), both on ground and on board.

4 Costs of environmental noise

4.1 Introduction

For policy making and large-scale studies on noise abatement, cost-benefit analysis (CBA) is a common tool, as will be explained in chapter 5. CBA requires that the benefits are expressed in monetary units. The monetarisation of the external impacts of environmental noise has received much attention in national, European and international research over the last 20 years. Various methods and techniques exists, that deliver different results with varying accuracy. We dedicate this chapter to the concept of monetarisation and we describe and compare the different methods that can be used.

4.2 Internal vs. external transport costs

Transport contributes significantly to economic growth and enables a global market [11]. Better transport leads to increased mobility, which is positive. On the downside, transport also has negative effects on society, on infrastructure and on the environment. So, besides the economic and social benefits, transport also leads to costs. Note that in our definition, transport 'costs' include all negative impacts of transport, even if they are not expressed in monetary terms. For a cost-benefit analysis (CBA), as explained in 5.2.4, all costs and benefits somehow need to be translated to their economic value. Since CBA is a common technique, preferred by many decision and policy makers, considerable efforts have been made in the past, and are still ongoing, to monetarise the social impact of transport, so as to quantify the economic benefits for noise abatement measures.

To quantify the costs of, we need to distinguish between:

- internal costs, or private costs: these are the costs paid by the user (traveller), including operating and fuel costs, wear/tear of his own vehicle, traveling fares for public transportation, taxes and charges. Costs for his own traveling time are also included, as well as insurance fees and accident costs borne by the user himself;
- external costs, or social costs: these reflect all costs that arise from the provision and use of transport infrastructure, including capital and investment costs, and maintenance costs due to wear and tear of public transportation vehicles and infrastructure. Also included are accident costs borne by other users and society, and the increased time costs for other travellers due to congestion. And finally, external costs also include the environmental costs and the costs for decreased health and wellbeing of the population.

The external costs are not borne, and usually not considered, by the transport users. One of the main objectives of policy makers and researchers in the transport sector is the "internalisation" of the external costs: how to make the external costs part of the traveling decisions made by the users? According to the welfare theory approach, internalisation of external costs by market-based instruments may lead to a more efficient use of Infrastructure, reduce the negative side effects of transport activity and improve the fairness between transport users [9].

This can be done directly through "command-and-control" regulation measures, such as low-emission zones in cities, or indirectly by applying market-based instruments, such as pricing strategies that promote the use of low-impact vehicles and traveling modes. Noise-differentiated access charges for rail and air transport are an example of such pricing strategies for environmental noise, but one may also think of noise differentiation in vehicle taxes, comparable to the EURO emission classes for heavy duty vehicles. Such instruments will put more pressure on automotive, rail and aircraft industry, who need to make an effort to produce more silent vehicles (and tyres). An increase of the vehicle or tyre price because of these measures could also be regarded as 'internalisation'.
Besides economic instruments, raising public awareness may help to reduce external costs by influencing the user's transport decisions.

4.3 Monetarisation methods

The EU handbook on External Costs of Transport [9][11] distinguished two general approaches for the economic valuation of environmental noise:

- **top-down approach:**
  The total noise costs are determined on a macro-scale (the whole country). The estimated number of people exposed to traffic noise is multiplied by an average WTP-value ("Willingness To Pay" for noise reduction) to estimate the noise costs due to annoyance, plus an average value for health costs, including absentee costs and loss of production if possible. To improve the estimation, noise classes (e.g. 50 – 55 – 60 – 65 – 70 dB) can be used, each with their own estimated number of people exposed and their own costs values.

- **bottom-up approach** (also known as Impact Pathway Approach (IPA)):
  The bottom-up approach starts from the micro-scale (the traffic flow on a particular route). Five steps are involved:
  - calculate the noise emission, in terms of time, location, frequency, level and source of noise;
  - calculate the L_{den} and L_{night} in dB(A), including the sound propagation depending on geographical location and other location-specific factors. The result is presented on a noise map;
  - use exposure-response functions (dose-effect relations) to calculate the total impact of the noise for several endpoints. Each exposure-response function presents a relationship between dB levels and negative impact endpoints, e.g.: annoyance, sleep disturbance, acute myocardial infarction and hypertension;
  - calculate an economic value for a unit of each endpoint of the exposure-response function. Estimates exist from existing valuation studies;
  - multiply the economic value of each unit of endpoint by the corresponding impact and aggregate the results.

The results of top-down and bottom-up approaches are different. A top-down approach results in <u>average</u> noise costs, while a bottom-up approach provides <u>marginal</u> noise costs (i.e. the extra cost from one additional vehicle). From a theoretical point of view the bottom-up approach is preferred in state-of-the-art CBA approaches, since marginal noise costs can be made dependent on traffic density, traffic composition, vehicle speed, geometry, etc. In tables III, IV and V, estimates for marginal noise costs are given, for road, rail and air traffic. Furthermore, figures are dependent on the population density and on the time of day (see figure 8).

However, these specific estimations are not very useful for internalisation strategies with regard to environmental noise: due to the logarithmic nature of noise, the increase of noise due to an extra vehicle becomes lower as the traffic intensity increases. A disadvantage of marginal costs is, therefore, that the cost is dependent on the traffic flow, higher when flow is small, lower when flow is high. In the examples from CE Delft (see tables III, IV and V), marginal noise costs are about 3 times higher in thin traffic flow than in dense flow. This fact makes the marginal costs approach less suitable for pricing strategies, because this would lead to traffic bundling (see [30]): it would be cheaper to drive on a route where noise levels are already high.
The bottom-up approach described in the EU handbook could be adapted to overcome this bundling issue if the 'marginal costs' are defined as the costs per extra dB, differentiated per category and as a function of speed, instead of per extra vehicle or vehicle-km. The issue may, therefore, not be so much an issue of the 'bottom-up' approach as such, but merely of the unit chosen for the marginal noise costs. In a marginal cost internalisation strategy based on the costs per dB, quietening the vehicle with a certain amount of dB directly leads to an economic value.
The bottom-up approach, however, takes significantly more time and data.

table III *EU averaged marginal noise costs for road vehicles in € per 1000 vkm, 2010 price level ([11])*

Mode	Time of day	Traffic type	Urban	Suburban	Rural
Car	Day	Dense	8.8	0.5	0.1
		Thin	21.4	1.4	0.2
	Night	Dense	16.1	0.9	0.1
		Thin	38.9	2.5	0.4
Motorcycle	Day	Dense	17.7	1.1	0.1
		Thin	42.7	2.7	0.4
	Night	Dense	32.1	1.9	0.2
		Thin	77.9	5.1	0.6
Bus	Day	Dense	44.0	2.4	0.4
		Thin	107.0	6.8	0.8
	Night	Dense	80.3	4.5	0.7
		Thin	194.7	12.7	1.5
LDV	Day	Dense	44.0	2.4	0.4
		Thin	107.0	6.8	0.8
	Night	Dense	80.3	4.5	0.7
		Thin	194.7	12.7	1.5
HGV	Day	Dense	81.0	4.5	0.7
		Thin	196.6	12.7	1.5
	Night	Dense	147.8	8.3	1.3
		Thin	358.2	23.1	2.6

table IV *EU averaged marginal noise costs for rail vehicles in € per 1000 vkm , 2010 price level ([11]).*

Mode	Time of day	Traffic type	Urban	Suburban	Rural
Passenger train	Day	Dense	273.4	12.1	15.0
		Thin	540.2	23.8	29.7
	Night		901.6	39.8	49.6
Freight train	Day	Dense	484.8	23.9	29.9
		Thin	1169.6	46.3	57.8
	Night		1977.6	78.3	97.7

table V *Marginal noise costs for aircraft operations in € per LTO (Landing/Take-off) , 2010 price level ([11]). Examples for Frankfurt (left) and Heathrow (right).*

Aircraft type	07L (easterly traffic)			25R (westerly traffic)		
	Day	Evening	Night	Day	Evening	Night
737-800	32.4	77.0	240.8	29.0	69.0	216.4
747-200	71.6	170.0	524.0	55.8	132.4	412.6
747-400	128.0	304.0	934.0	113.6	269.4	836.6
767-300	42.6	101.2	316.0	34.6	82.0	257.2
A 300-62	77.8	184.6	572.0	76.6	181.6	567.8
A 319	14.6	34.4	108.8	12.8	30.6	96.6
A 320	26.0	61.8	194.4	23.2	54.8	193.0
A 340	51.6	122.4	385.8	54.0	127.8	403.4
ATR 72	7.2	17.2	53.8	1.6	3.8	11.8
DHC 8	2.6	6.2	19.6	0.2	0.4	1.4
EMB 145	7.0	16.6	52.0	2.2	5.2	16.2
MD 82	9.2	21.8	68.6	3.4	8.2	26.2

Source: Ökoinstitut/DIW (2004).

Aircraft type	€ per LTO
A210	92.3
A340	111
Bae146	21.6
B737-100	326
B737-400	49.1
B747-400	242
B757	63.5
B767-300	77.9
B777	47.6
F100	17.3
MD82	70.7

Source: TRL (2001).

Municipality	E20 length km	Pop. dens. inh./km^2	Traffic flow veh./24h	MC €/km
Partille	8	591	29000	0.0741
Lerum	17	146	19000	0.0120
Alingsås	21	78	19000	0.0064
Vårgårda	23	26	11000	0.0012
Essunga	5	24	8000	0.0008
Vara	32	23	8000	0.0008
Skara	23	42	9000	0.0016
Götene	17	32	8000	0.0011
Mariestad	41	40	11000	0.0019
Gullspång	17	17	7000	0.0005
Total	203			0.0055

figure 8 *Example of marginal costs of road traffic noise along a part of the E20 Gothenburg direction Örebro. Note how MC depends on population density and traffic density (source: Andersson and Ögren [26]).*

4.4 Willingness To Pay (WTP)

4.4.1 General concept

Both in the top-down approach for estimating average noise costs and in the bottom-up (IPA) approach for estimating marginal noise costs, the noise levels at some point must be translated to a monetary value. Common methods for valuation of environmental noise aim at estimating the Willingness To Pay (WTP). The Willingness To Pay, in general, expresses how much money people would be willing to pay for a certain improvement in their well-being. An alternative is the Willingness to Accept (WTA), which usually expresses how much money people would accept as compensation for a particular burden.

The Willingness To Pay is usually expressed as a monetary sum per dB per person per unit of time. For instance, Navrud [34] gives a summary of contingent valuation studies that rate the WTP for road traffic noise in €/dB/household/year, with values ranging from 2 to 99 (2001 price level). A few values were also given for aircraft noise, ranging from 8 to 959 €/dB/hh/year.
The EU Working Group on Health and Socio-Economic Affairs, based upon the same study by Navrud, advised a value of 25 €/dB/hh/year (2001 price level), as an average European value for road noise, valid between approximately 50 and 75 dB(A)[3] [35]. Different units are sometimes used in other studies, but most studies use the currency/dB/hh/year unit, or translate their results to this unit.
The willingness to pay depends on the income of the people involved; this dependency should, if possible, be accounted for. Examples of income-dependent WTP values exist (see section 6.3.7). The more recent values reported in the HEATCO project in 2006 ([28][29]), although not income-dependent, distinguish WTP values for different European countries. The HEATCO values should, at this time, be considered as the state of the art.

It should be noted that the WTP only includes the noise impact that people are actually aware of. That generally includes only annoyance during waking hours and self-reported sleep disturbance (awakening). As people become more aware of long-term and indirect health effects, the WTP may increase as a result.

[3] The WG-HSEA report actually states the validity range to be “between 50/55 Lden and 70/75 Lden”. The min/max values differ between studies.

4.4.2 Revealed preferences (RP) vs. stated preferences (SP) methods

To determine the WTP for annoyance, one can either use the Stated Preference (SP) method, in which questionnaires are used to ask the people how much they would be willing to pay for a certain amount of noise reduction (contingent value approach). Or, one may use the Revealed Preferences (RP) method, for instance using Hedonic Pricing.

Stated Preferences (SP) methods include:
- Contingent Valuation (CV), where people are asked directly how much money they would be willing to pay for a certain reduction in perceived noise levels, usually in some hypothetic situation;
- Conjoint Analysis (CA), where people are asked to rank different alternatives in noise situations on a point scale;
- Choice Experiments (CE), where people are asked to choose between direct discrete choices; one may choose A over B and B over C, which then automatically means that A is favoured over C as well.

Most SP studies use contingent valuation, since this is the easiest way to attach a monetary WTP value to the outcome. Choice experiments, although harder to design and to analyse statistically, may reduce the required sample size compared to CV [34]. For all SP research, it is important to design the survey well. It is difficult, for instance, to describe the reduction in noise level in such words that it can be well understood and matches the expectations of the participants. One should not ask for the WTP for a 3 dB noise reduction, but for a 30% decrease in annoyance. Or, one could ask for the WTP for a noise reduction equivalent to a 50% lower traffic flow, or “traffic on an average Sunday afternoon”. Other difficulties may arise if it is not clear how the financial arrangements would be made. And also, people may not respond well to the concept of WTP, since they feel that they should not have to pay to reduce noise caused by others.

An alternative is to use a Revealed Preferences (RP) technique. In general, the concept of RP is that the preferences of the public can be measured by observing their purchasing of a certain related good. The observation is usually done by relating the quantity of interest to developments in the price of the related good (Hedonic Pricing). For environmental noise, it is common to establish a relation between the (differences in) environmental noise levels and the local real estate prices (house prices or rents). Other RP techniques exist, such as estimating the avoidance costs, but examples are few.

<u>Hedonic Pricing (HP)</u>
Hedonic pricing is often applied for monetarisation of environmental noise by looking at the impact of noise on the market value of real estate (prices and/or rents). The effect is usually expressed as a Noise Depreciation Index (NDI) or Noise Depreciation Sensitivity Index (NDSI), which indicate the average percentage change in property prices or rents per decibel, above a certain threshold. The total economic loss is expressed as:

$$loss = NDI * \sum_i (L_i - L_{th}) * P_i$$

where L_i is the noise level (f.i. L_{den} or $L_{24\text{h}}$) at a particular dwelling i, L_{th} is the threshold level above which noise depreciation occurs and P_i is the price of the dwelling. In this definition, the WTP is then the average loss per dwelling/household.

The general advantage of RP methods is that they objectively measure the actual behaviour of the public, instead of relying on their own personal judgment in a hypothetical situation. Implicit prices used in HP, however, are sensitive to model specification (e.g. the separation from other external effects that impact the price), estimation procedures (including choice of functional form) and the functional form of the relation between noise levels and price (e.g. a linear/lognormal relation or Box-Cox transformation) [34]. Also, it is assumed that the respondent actually had information about the noise level at the dwelling when bidding, and that the housing market had perfect competition and zero transaction costs.

In Hedonic pricing, the decrease of house prices and rents is used merely as an instrument to measure the economic value that can be attached to noise. But the actual economic loss of the real estate property value is, in fact, an impact on the total external costs of transport in itself, that may not be fully correlated with the perceived annoyance or estimated health impacts. And the effect of traffic noise on the value of unoccupied land, for instance, is an economic aspect in itself, that will not be included if one only considers the number of annoyed people. It is important to clearly indicate in an external costs assessment what economic endpoints are actually included, and the monetarisation values used in the assessment should match these endpoints.

4.5 Health costs

In the monetarisation of the external impact of environmental noise, two major aspects considered are:

1 Annoyance
2 Health effects.

The WHO definition of health [12] includes the annoyance, since health is defined as a total state of well-being and annoyance therefore is considered a decrease in health. However, it is generally assumed that these two effects are, from the public's point of view, independent, i.e. the potential long term health risk is not taken into account in people's perceived noise annoyance [29]. And even if people are aware of the health risk, the health costs are covered by (public) health insurance so people may not be willing to pay for these costs. The WTP established through Hedonic Pricing, therefore, will not include the health costs: people do not cognitively include the positive or negative impact of noise on their health when bidding for a house. Sleep disturbance is partially included in Hedonic Pricing, since people may actually wake up from traffic noise (i.e. 'self-reported' sleep disturbance). Health research using polysomnography shows that traffic noise also influences the unconscious sleep, leading to less deep sleeping and a lower restorative power of sleep. These effects are assumed not to be included in the WTP established with RP methods, and need to be included in the health costs.
If the WTP is established through an SP method, it depends on the questionnaire if health costs are included. In most cases, people are only asked to value a reduction in perceived annoyance and possibly sleep disturbance, not a reduction in their chance to experience hypertension or myocardial infarction. And if the questionnaire includes the WTP for these health risks, they express the costs that people feel are equivalent to their reduced quality of life, which may be quite different from the actual costs for medical treatment.

Existing work, has shown that quantifiable health effects are of minor importance compared to the WTP for reducing disamenity and annoyance [29]. Nevertheless, methods do exist to estimate the costs of health-related impacts of noise, not including annoyance.

4.5.1 Value of a statistical life (year)

A direct relation between the increase in health-related costs (doctor costs, hospital bills and decreased productivity due to health issues) is thinkable, but it is quite difficult to separate the noise-related effect from other external impacts from the traffic (e.g. air pollution). The most likely option for monetarisation of health impacts is to use the results from cost-utility analysis using DALY (see 5.2.3) and then valuing the DALY's with a monetary value: the value of a statistical life (VSL) or the value of a statistical life year (VOLY). Actual values for the VSL exist as a European average. For instance, the HEATCO and UNITE studies [29][30] provide VSL values. CE Delft in 2011 used a value of 1.67 M€ (price level 2008) as an average value for EU-27 (incl. NO, CH) [10]. More recent values are given in an OECD study published in 2012 [32][33] and should be considered as the current state of the art. The values found in this study are given in table VI.

table VI *Average base value and minimum/maximum for the VSL for EU27, EU28 and the average for the 53 WHO European Region countries (from www.heatwalkingcycling.org[4])*

	VSL in million € (price level 2011)		
	base value	minimum	maximum
average EU27	**3.39**	1.69	5.08
average EU28 (including Croatia)	**3.37**	1.69	5.06
average WHO European Region (without Andorra, Monaco, San Marino, Turkmenistan and Uzbekistan)	**2.49**	1.24	3.73

All of these studies, however, highlight that significant differences between countries may arise as a result of demographic differences, welfare level and risk characteristics. A study into international empirical VSL values for road traffic [31] show a range from US$ 150.000 to US$ 36 million (price level 2005).

It is therefore advised to use country-specific values [36]. If the WTP for annoyance is determined separately, using the RP or SP methods described above, the exposure-response function and contribution from annoyance should not be included in the DALY calculation, so as to avoid double counting.

Exposure-response functions for the most important health effects are described in the WHO report [12]. An updated version of the WHO community noise guidelines is expected to be presented in 2018, which may contain new exposure-response functions for existing noise/health relations as well as functions for new health endpoints, based on an extensive review of European and international studies.
Country-specific exposure-response functions are recommended, however, as the responses to a certain exposure differ from country to country. Values for the VSL are also common, under the assumption that VSL values from other research subjects (e.g. safety, drug/medicine research, smoking) can be directly transferred to the case of environmental noise. This assumption, that the economic loss for a particular disease is not be related to the cause of the disease, seems reasonable. VSL value suggested above actually comes from an economic assessment of traffic accident risks, but it has also been applied, for instance, to air pollution.

4 http://www.heatwalkingcycling.org/index.php?pg=requirements&act=vsl&b=1

5 Overview of decision methods

5.1 Introduction

In the previous chapters we have addressed the external impacts of traffic noise on public health and annoyance. We have addressed various noise abatement measures, each of which have a particular LCC cost level. In chapter 7, we will list a number of other criteria involved in the decision process.

The decision process for noise abatement measures usually involves some kind of "*cost/benefit analysis*", although it is not always clearly expressed what is the exact method used. The 'cost/benefit' analysis actually involves a family of different methods, each of which have their own characteristics. And each of these methods may actually give different results.

Table VII gives an overview of five different methods that will be discussed and compared in this report. In section 5.2, each of the methods will be explained in more detail. We will also provide a numeric example where each of the methods is applied on a hypothetical situation where a choice between various noise abatement measures is to be made. It will be clear from the example that the selection for a particular method may lead to a different outcome, with regards to the noise abatement measures that are finally selected.

table VII *Overview of decision methods*

method	costs of measures	benefits / other criteria	description
cost-minimisation	costs	-	the output is fixed, to the required noise reduction; costs are then the only variable parameter
cost-effectiveness (CEA)	costs	single parameter	for noise, the output parameter is usually the noise reduction (in *dB x persons*)
cost-utility (CUA)	costs	single parameter describing various aspects of public health (utility)	the health impact is expressed in DALY or QALY units
cost-benefit (CBA)	costs	multiple criteria expressed in monetary units, summed to a single value	every benefit is translated to monetary units, e.g. using WTP values from hedonic pricing methods
multi criteria design analysis (MCDA)	costs	multiple criteria, each on a different arbitrary scale	every benefit, as well as the costs, are scored and then combined and compared on one numeric scale using weighting factors

5.2 Decision methods for noise abatement measures

5.2.1 Cost-minimisation analysis

In a cost-minimisation analysis, the costs are the only variable. It can be used to compare different measures that deliver the same result, with the goal of finding the cheapest alternative. In a noise abatement setting, the noise reduction required for a particular situation may be fixed, often based on the noise legislation. Any noise abatement measure is accepted, as long as it generates a noise reduction of X dB (or more). In procurement of the noise measure, price is the only criterion used to select a candidate for contracting.

Finding the cheapest alternative will often require a comparison of multiple alternative noise measures or combinations of measures. For instance, optimisation of the noise barrier height along the route may lead to lower costs: a 6 m high noise barrier of 2 km long may be lowered to 4 m at certain sections where there are less houses behind it. Noise barrier optimisation calculation routines exist for this purpose[5].

5.2.2 Cost-effectiveness analysis

In a cost-effectiveness analysis (CEA), the goal is to optimise the balance between costs on one side and one particular, measurable output quantity on the other side. In health related problems, including environmental noise, the output quantity is often the life expectance, or the life years gained from a particular remedy, but it may also be the number of cases for a particular disease, such as hypertension or stroke. For a particular noise abatement situation, the output quantity may also be the noise level or the noise reduction, just as in the cost-minimisation analysis.

In addition to the cost-minimisation the objective is not just to find the cheapest solution, but to find an *optimal* solution, based on the ratio between incremental costs and incremental returns. In general business analyses, the 'law of diminishing returns' or the Pareto rule (80%/20%) are examples of effectiveness optimisation.

For instance, applying rail dampers on a certain track section reduces noise levels at 95% of the surrounding buildings below the accepted limit. For the remaining 5% of the buildings, the only option is to build a high noise barrier. The noise barrier could be considered too expensive, given the limited extra gain.

<u>Example 1</u>
An example is given in table VIII for a hypothetical situation. The situation is a suburban road section of 5 km length. The road has 2 x 2 lanes, with a total width of 25 meters. Along this road section are 400 households that suffer from road traffic noise. Several noise abatement measures are considered:

- Two different low-noise: low-noise surface 1 is a thin porous asphalt layer that reduces the noise emission by 3.5 dB(A); low-noise surface 2 is a double-layer porous asphalt that reduces the emission by 6 dB(A).
- A noise barrier of 3 m, which reduces the noise by 10 dB(A) for half of the dwellings close to the road and 5 dB(A) for the other half.
- A combination of the 3 m noise barrier with low noise surface 2.
- A combination of a 6 m noise barrier and low noise surface 2.

The costs for the noise abatement measures are given as life cycle costs, including initial investment and 30 years of maintenance. The actual numbers are taken from Dutch standard cost estimates (price level 2009). The noise reduction is the sum of the noise reduction for each dwelling over all of the 400 dwellings in the project area, measured in dB * household. Bringing the level at each of 400 dwellings exactly down to the desired legal threshold in this example corresponds to a total noise reduction of 3500 dB*hh.

[5] see for instance the Austrian OPTIWAND project: https://www2.ffg.at/verkehr/projekte.php?id=886&lang=en

table VIII *Example 1: Costs vs. noise reduction for different noise abatement measures*

		costs (LCC) [M€]	total reduction [dB*hh]	required reduction [dB*hh]	effectivity
A	no noise abatement measures	0	0	3500	0%
B	low-noise surface 1	4.9	1200	3500	45%
C	low-noise surface 2	9.9	2600	3500	77%
D	3 m noise barrier	20.7	3400	3500	97%
E	low-noise surface 2 + 3 m barrier	30.5	5800	3500	161%
F	low-noise surface 2 + 6 m barrier	48.2	6800	3500	200%

If the decision method would be cost minimisation, then the decision would be to select the cheapest noise measure that fulfils the legal requirements. In this example, that would be option E: a low noise surface type 2 combined with a 3 m high noise barrier.

If the decision method would be cost effectiveness, then the best option is not so obvious. In this particular situation, a likely option would be D, based on the argument that this option nearly fulfils all legal requirements; option E would be considerably more expensive, and the result would have a 61% higher noise reduction than actually required. If we disregard the legal limits, however, then option D is not so likely. The graph in figure 9 shows that the extra costs of option D with respect to option C are actually quite large compared to the extra noise reduction, so option C may be considered more cost-effective.

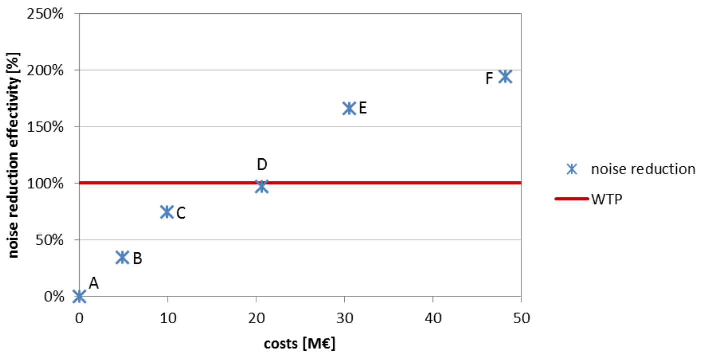

figure 9 *Example 1: Effectivity (noise reduction as a percentage of the legal requirement) vs. costs*

5.2.3 Cost-utility analysis

Cost-utility analysis (CUA) is a method similar to cost-effectiveness, most often used in health research. In a cost-utility analysis, the output parameter is not a single measurable health quantity, such as the life expectancy, but a 'virtual' quantity that combines separate health-related quantities in a single unit. Usually, the units used are DALY (Disability Adjusted Life Years) or QALY (Quality Adjusted Life Years), both of which aim to estimate the number of 'healthy life years'. In their 'burden of disease from environmental noise' report [12], the WHO use DALY's, defined as "the sum of the potential years of life lost due to premature death and the equivalent years of 'healthy' life lost by virtue of being in states of poor health or disability". To calculate the impact of environmental noise on health, the amount of healthy years lost are calculated for a number of noise-related impacts and diseases, each of which has their own disability weight (DW) factor, and added to the years lost to premature death (which has a DW of 1). High annoyance is included by the WHO as a negative impact of noise on health, with a DW in the order of 0,01 to 0,12; mild or low annoyance is not included in the DALY calculation. Calculations for the different health components are performed using dose-effect relations that have different environmental noise levels as input. Besides the different output parameter, the cost-utility analysis has a goal similar to the cost-effectiveness analysis, aiming to optimise the balance between cost and health.

Example 2

For the example from the previous paragraph, we have also estimated the health impact of the various noise abatement options in DALY. The result is given in table IX and figure 10. The DALY amounts have not been calculated using the actual WHO method, but for the sake of our example we have just a simple function that increases the health impact with noise level. The function is slightly nonlinear and considers the health impact to be zero below 50 dB(A) (see figure 10, right graph). Since the area considered is small, the actual DALY amounts are very low. The values are therefore presented as micro-DALY.

The health impacts are shown as a function of noise abatement costs in figure 10 (left graph). Judging from these blue points, option D is not very likely, since the extra health benefits are limited with respect to option C. Option E, however, could be considered a good option from a cost-utility point of view. The costs for option E are three times the costs of option C, but the health impact is reduced to approximately one quarter.

table IX *Example 2: Costs, noise reduction and health impact for different noise abatement measures*

		costs (LCC) [M€]	total reduction [dB*hh]	effectivity	health impact [10^{-6} DALY]
A	no noise abatement measures	0	0	0%	512
B	low-noise surface 1	4.9	1200	45%	389
C	low-noise surface 2	9.9	2600	77%	278
D	3 m noise barrier	20.7	3400	97%	214
E	low-noise surface 2 + 3 m barrier	30.5	5800	161%	75
F	low-noise surface 2 + 6 m barrier	48.2	6800	200%	36

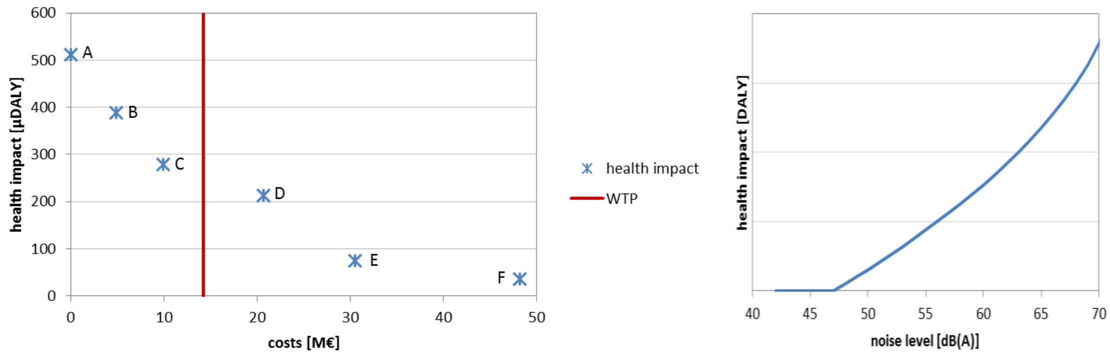

figure 10 *Example 2: <u>left</u>: health impact (in micro-DALY) vs. costs; red line indicates WTP for all inhabitants; <u>right</u>: figurative health impact function*

5.2.4 Cost-benefit analysis

In a cost-benefit analysis (CBA), not only the costs but also all the benefits are expressed in monetary units. Some benefits are directly related to a monetary value, such as reduced hospital costs due to lower occurrence of diseases.
Benefits that are time-related, such as effects on mobility (traveling times, traffic jams), are often expressed in money. Travelling time influences transport costs for goods as well as people, both for business and leisure travel. Due to the large amount of commuters, a few minutes of time increase

or decrease may lead to high economic value in these analyses. Discussion on the economic value of leisure time, however, exists.
Other benefits, such as the reduction of annoyance or the increase of safety, are not directly expressed in monetary units and need to be ‘monetarised’. Monetarisation is quite common for environmental noise issues, although scientific and ethical objections exist. Different techniques are explained and compared in paragraph 4. Monetarisation may be quite difficult for more subjective aspects, such as the aesthetic value of noise abatement measures or the perceived positive or negative impact on the landscape.

In cost-benefit analysis, the cost and benefits resulting from a noise abatement measure can be directly compared and combined. The balance between cost and benefits may be optimised by looking at the direct difference between costs and benefits. If the net monetary difference is positive (costs are lower), then the noise abatement measure may be accepted; if it is negative, it may be considered ‘too expensive’. Or, one may look at the ratio of costs over benefits, similar to the cost-effectiveness analysis. The noise abatement measure may be accepted if the C/B ratio is low. Or, one may look at the change in C/B ratio from one measure to another.

<u>Example 3</u>
In our example, we have also monetarised the external costs of annoyance by using an EU 2001 average Willingness-To-Pay value of 25€/person/dB/year, over a period of 30 years (the same period we have used for the LCC costs).

The total external costs are calculated as follows:
- determine the noise level $L_{\mathrm{den,hh}}$ for each household,
- determine the number of people for each household $N_{\mathrm{P,hh}}$, or use a generic value for all households;
- calculate the total external costs by summing over all households as follows:

$$total\ external\ costs = \sum_{hh} 25€ * N_{P,hh} * \left(L_{den,hh} - 50\right) * T,$$

where T is the chosen time period, which is 30 years in our example. In our example, the number of people per household is assumed to be 2.1.

The EU 2001 WTP value is defined 25€ per person, per dB above 50 dB. This value only includes annoyance and not the health costs. We have estimated the other health-related costs to 50% of the WTP for annoyance.
If we apply this calculation to the same noise levels used in the previous examples, the total external costs are estimated to be 14.2 million Euro. If we compare this amount to the actual costs for the various noise abatement measures, we conclude that option C is a good choice from a cost-benefit perspective. Options D, E and F are likely to be considered too expensive.

5.2.5 Multi decision criteria analysis

Multi decision criteria analysis (MCDA) is a form of multi-criteria analysis that combines costs and other decision criteria into an decision evaluation process, which includes attributing a score, on an arbitrary scale, to each of the criteria and assigning weighting factors. Costs are also evaluated on a non-monetary scale. Different options are compared based on their total weighted score. Choosing an option can be done by choosing the option with the highest score. It is also possible to separate the costs from the other criteria and perform an effectiveness evaluation. This approach would then be similar to the cost-utility analysis, using the weighted combination of the other criteria as a utility measure.

The difference with cost-benefit analysis is that all criteria, both on the cost and on the benefit side, are combined on an arbitrary, non-monetary scale. Benefits that are difficult or impossible to monetarise can easily be integrated in the decision making. The MCDA analysis does require that weighting factors are derived and assigned for each criterion, which is a step that CBA analysis does not have. In MCDA analysis, it is common to perform a sensitivity analysis to investigate the effect of choosing different weighting factors on the ranking of the different options. A good description and application manual for MCDA methods can be found in [25].

Example 4

To further explain the MCDA concept, we may look again at our example. In the MCDA version of this example, we include different criteria:

- costs: the LCC costs for each noise abatement measure, just as in the previous examples;
- annoyance: the noise levels have been translated to annoyance levels: severe (> 65 dB), moderate (60 – 65 dB) and slight (55 – 60) dB. The 'overall' annoyance has been calculated as 100% of the severe annoyance, 50% of the medium annoyance and 20% of the slight annoyance. This has been done because the concept of 'annoyance' is better understood by the public than the noise level in dB, which improves the estimation of the weighting factors;
- roadside aesthetics: the opinion of the road user is taken into account by including a score for the visual landscape, as seen from the roadside;
- social security: for the houses close to the road, a noise barrier may increase their sense of social security; the noise barrier not only reduces the road noise, but it also removes the traffic from the visual environment, which may enhance the sense of safety and perceived annoyance;
- maintainability: a separate score has been included for maintainability; this does not include the costs for maintenance, but it expresses the amount of road work and the increase of traffic jams, due to repaving or noise barrier maintenance work.

The values for roadside aesthetics, social security and maintainability could come from questionnaires or Choice Experiments (see 4.4.2), conducted with the inhabitants and the road users. In this example, these criteria have been rated at a scale from 0 to 100. All values are given for the various noise abatement measures in table X. For the MCDA comparison, all values are translated to an arbitrary scale from 0 (least favourable) to 10 (most favourable). The lowest value is given 0, the highest value is given 10 and all other values are linearly interpolated. The score for costs, for instance, is 10 for option A (no measures) and 0 for option F (6 m barrier + low-noise pavement type 2). The result is given in table XI.

Also needed for the MCDA results are weighting factors. Three sets of weighting factors are given in table XI, expressed as a percentage from 0% to 100%. The total score for each set of weighting factors are given in the right three columns of table XI. Setting the weighting factors could also be done by questioning the inhabitants and road users, by ranking or rating the importance of the different criteria, but policy makers may also have a say in this themselves.

table X *Example 4: values for costs, annoyance and other criteria for several noise abatement measures*

	costs (LCC)	annoyance				roadside aesthetics	social security	maintainability
	[M€]	% severe	% moderate	% slight	overall			
A: no noise abatement measures	0	50%	0%	50%	60%	100	0	100
B: low-noise surface 1	4.9	50%	0%	0%	50%	100	0	60
C: low-noise surface 2	9.9	0%	50%	0%	25%	100	0	40
D: 3 m noise barrier	20.7	0%	0%	50%	10%	20	100	90
E: low-noise surface 2 + 3 m noise barrier	30.5	0%	0%	0%	0%	20	100	35
F: low-noise surface 2 + 6 m noise barrier	48.2	0%	0%	0%	0%	0	100	35

table XI *Example 4: values for costs, annoyance and other criteria for several noise abatement measures*

	costs	annoyance	maintainability	roadside aesthetics	social security	score WF I	WF II	WF III
A: no noise abatement measures	10.0	0.0	10.0	10	0	20.0	12.0	15.0
B: low-noise surface 1	9.0	1.7	3.8	10	0	17.6	12.7	13.3
C: low-noise surface 2	8.0	5.8	0.8	10	0	19.2	15.8	13.6
D: 3 m noise barrier	5.7	8.3	8.5	2	10	24.3	16.4	15.0
E: low-noise surface 2 + 3 m noise barrier	3.7	10.0	0.0	2	10	19.7	16.1	11.7
F: low-noise surface 2 + 6 m noise barrier	0.0	10.0	0.0	0	10	15.0	12.0	7.5
weighting factors I	100%	100%	50%	50%	50%			
weighting factors II	100%	100%	0%	20%	20%			
weighting factors III	100%	50%	25%	25%	25%			

In the first set of weighting factors (WF I), for instance, costs and annoyance are weighted equally at 100% and the other three factors have lower weighting factors of 50%. In the second set (WF II), we have set the weighting factor for maintainability to zero, so it has no influence, and reduced the influence of roadside aesthetics and social security. The third set (WF III) is equal to the first set, but with twice as much weight of the costs with respect to the other criteria.
The result from our MCDA example is that option D achieves the highest score, for all three sets of weighting factors. For WF I and WF II, option E scores second-best, although the difference is smaller for WF II. For WF III, where we have made costs more important, option D also scores best, but it turns out that doing nothing (option A) actually scores just as good.

It is clear from this example that MCDA does allow quite different criteria to be included in the analysis while still providing clear results. The weighting factors and scores, of course, largely determine the results. It is important for the acceptance that all relevant stakeholders are included in setting the scores and weighting factors.

5.3 Advantages and disadvantages

The various decision making methods explained in the previous section are:
1 Cost minimisation (CM)
2 Cost-effectiveness analysis (CEA)
3 Cost-utility analysis (CUA)
4 Cost-benefit analysis (CBA)
5 Multi-decision criteria analysis (MCDA)

From CM to MCDA, the decision making process becomes more complex on one hand, and will therefore take more research, time and budget. At the same time, the possibility to include more criteria increases. CM only looks at costs and aims at finding the cheapest solution. CEA aims to find the optimal solution for one particular criterion. CUA aims to find the solution that is optimal for a combination of criteria that determine public health (in DALY's). CUA is already quite complex, since it requires the translation of noise levels into a combined health effect. The difficulty is finding the appropriate exposure-response functions (ERF's) for each health endpoint (each different disease), especially since evidence shows that the ERF depends on the traffic source and may be different for road, rail or air traffic. However, the DALY approach builds on an extensive and currently growing research base, in which the effect-response functions for the most important health effects exist.

CBA and MCDA are both more complex methods, which compared to each other have pros and cons. A SWOT comparison of both methods is given in table XIII below.

CBA is less complex method-wise and can be more easily explained. People understand the concept of money and may be more easily convinced by the fact that a noise measure is considered too expensive if the costs exceed the monetary benefits. The main complexity with CBA is that every criterion that one wants to include requires monetarisation: if the benefits cannot be expressed in money somehow, they cannot be included in the analysis. Criteria for annoyance and health effects have received considerable scientific attention, but evidence shows (e.g. [34]) that the WTP values for road, rail and aircraft noise differ greatly between studies, which shows that monetarisation is difficult. For some of the other criteria in section 2.1, such as social, cultural and aesthetic criteria, monetarisation may be even more difficult. An overview of decision categories and criteria, with an indication of the difficulty for monetarisation, is given by Paolo Beria et al. [37]. Another difficulty with monetarisation is that it may be considered unethical to value aspects such as health or damage to the environment, and some may feel that these aspects should be avoided at all costs. This may be a problem from the scientific point of view, since it may affect the possibility or the outcome for WTP research, but it may also lead to a lower acceptance of the decision process by the public: they may reject the eventual decision because they disapprove the chosen method.

MCDA is a more abstract method, which needs weighting factors for each criterion that need to be established and tailored for each specific decision situation. This is a disadvantage compared to CBA, where the monetary values in CBA are more generic and can be transferred, with precaution and within certain limits, from one study to another. Its higher abstraction level also requires more effort to explain the method and the results. In MCDA, one cannot make much use of existing values research base. MCDA, at this moment, is also a method that is less common, which makes it more difficult for decision makers to apply. The establishment of weighting factors in MCDA requires expert judgment and more subjective decisions. The lower objectivity and lower scientific support may lead to a lower acceptance of the outcome. The fact that the weighting factors can be tailored to the situation and to the local public may also be used as an advantage, since it allows for greater public participation if the people are actually involved in setting the balance between the criteria. It also allows decision-makers to emphasize certain policy aspects by giving greater weight on certain criteria; this is not possible in CBA.

table XII SWOT summary of cost-minimisation, CEA and CUA methods

	Cost-Minimisation (CM)	Cost-Effectiveness Analysis (CEA)	Cost-Utility Analysis (CUA)
Strengths	▪ Simple and fast ▪ Only one right answer	▪ Relatively simple ▪ Accurate	▪ Method is well described; dose-effect relations and fall-back DW values are available ▪ Relatively easy to execute
Weaknesses	▪ Benefits are disregarded ▪ May lead to inefficient use of available budget	▪ Selection of ‘most effective measure’ may be subjective (depending on implementation) ▪ No consideration of additional benefits	▪ Limited accuracy, mainly of disability weights ▪ Selection of ‘best measure’ may be subjective
Opportunities	▪ Easy to explain ▪ Inexpensive to execute	▪ Optimal distribution of available budget ▪ Well-fit for legislation (limited complexity vs. high effectiveness)	▪ Focus on health/annoyance leads to higher acceptance ▪ Well-known and internationally accepted
Threats	▪ Low public involvement ▪ Focus on costs alone may lead to lower acceptance	▪ Low public involvement	▪ For small-scale projects, health effects may show to be limited (‘milli-DALY’)

table XIII *SWOT summary of CBA and MCDA methods*

	Cost-Benefit Analysis (CBA)	Multi-Decision Criteria Analysis (MCDA)
Strengths	▪ Direct comparison between costs and benefits in the same units ▪ Independent from expert judgment and policy considerations ▪ Consistent and transparent	▪ Any criterion can be included and quantified ▪ Sensitivity analysis is relatively easy; allows for evaluation of the accuracy of results
Weaknesses	▪ Requires monetarisation: criteria that cannot be monetarised cannot be taken into account ▪ May be inaccurate; accuracy is difficult to investigate	▪ Requires development and tailoring of weighting factors for each project; values and results cannot be transferred between situations
Opportunities	▪ Easy to understand an explain to the public; people naturally understand monetary units ▪ Extensive experience and existing research base with fall-back values	▪ Allows for public participation and democratic decision-making ▪ Allows for emphasis of policy aspects
Threats	▪ Monetarisation is difficult for some criteria; new studies take time and budget ▪ Ethical objections against monetarisation of health and environmental impacts reduce the acceptance of the method and the outcome	▪ Weighting factors are potentially subjective and ambiguous; may lead to lower acceptance of the outcome ▪ More difficult to explain method and results

5.4 Recommendations of best methods

The choice for the best decision-making method depends on various factors. The most important factors are:

- The questions that need to be answered, which could be:
  - Is it appropriate and/or required to apply a certain noise abatement measure or not?
  - Which of several different noise abatement measures, or combinations of measures, are the most appropriate/suitable be chosen for a particular project?
  - How much budget is available for noise measures within a project?
  - What is the effect of a certain policy change for noise abatement, on society and on the budget?
- The geographic scale of the noise problem, ranging from a single street, a city block or district, a particular highway/track section, a completely new road, rail or flight route, or a large agglomeration, to a national or international scale;
- The criteria to be involved: the number of different criteria, as well as the content and the difficulty to monetarise;
- The limits, or the amount of freedom, set by the legislation;
- The desired amount of public awareness or involvement;
- The amount of time and research budget available.

5.4.1 Selecting the best method

As a first principle, we recommend to keep it simple. If the project is small and the noise levels are set clearly by legislation a Cost Minimisation analysis may be enough. If you want to investigate if a little extra effort could resolve in a relatively large social improvement, or if you are not spending a great amount of budget for just the last dB, you could use Cost Effectiveness. In practice, we see that some consideration of the effectiveness is needed to avoid high costs to bring all dwellings below the desired limit: for instance reducing noise at the top floor of a high apartment building may require extremely high noise barriers. Cost Minimisation, therefore, should not regarded as 'best practice'.

With regards to Cost Utility, Cost Effectiveness and Cost Benefit analysis, a comparison is made in [6], comparing these three methods in terms of:

- implementability: How well can the method be prescribed and legally implemented?
- simplicity: How easily can the method be used?
- flexibility: Can other criteria be easily included?
- accuracy: How reliable is the outcome?
- objectivity: Is the outcome independent on judgment and policy choices?
- plausibility: Will people understand and accept the outcome?

A relative score for each of these properties is given in table XIV below.

table XIV *Advantages and disadvantages of CEA, CUA and CBA (from [6])*

property	Cost Effectiveness	Cost Utility	Cost Benefit
implementability	+	-	0
simplicity	+	+	-
flexibility	-	-	+
accuracy	+	-	- / --[6]
objectivity	-	0	+
plausibility	-	+	+

All methods presented in the table are used in practice but one can distinguish situations where one method will perform better than the other. The following best-practice is advised to choose the appropriate method:

- Cost Benefit Analysis is the only method that translates the benefits into monetary units. It is the only method to give an absolute and objective answer to the question "What is the effect of noise on economy?". It is most suitable for *large-scale projects or (inter)national policy decisions*. It is complex and quite inaccurate, so the result requires documentation and clear indications of the monetary values used and the bandwidths around them. Results can quite easily be explained, since the concept of money is well understood.
- Cost Effectiveness Analysis is about fair and transparent distribution of budget. It can be implemented in regulations (as is done in several countries) and once implemented, it is fairly simple to use. It is most suitable to apply in *large or small scale projects*, to make sure that people experiencing the same noise levels receive an equal treatment. The absolute height of the budget needs to be set by policy makers, using other means, which makes it less objective. Also, it uses some arbitrary measure of effectiveness that cannot be directly related to health and annoyance, which people may not understand and accept.
- Cost Utility Analysis results in direct health benefits, either as separate health endpoints or in DALY units. Using DALY's, the outcome may be used to compare the noise to other health-related aspects, such as air quality. It may even be integrated in full life cycle assessment methods, such as the recently updated ReCiPe [38], although until now noise has not yet been included. It is objective, since it is based on commonly accepted international studies by the WHO, and it performs well with respect to public acceptance. It could in principle be used for legal implementation, but one should realize that values and outcome will change over time as research in the field progresses.

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[6] Accuracy for CBA depends on the monetarisation approach: using WTP, the result is inaccurate (-); using the DALY / VSL approach, the result is even more inaccurate since the inaccuracy in the VSL adds to the inaccuracy in the DALY itself

In CM, CEA or CUA, other criteria, such as safety, technical limitations, aesthetic design criteria, etc. are not involved in the method. Some of these criteria may be formulated as strict limitations, for example: “You cannot build a noise barrier on this bridge, because the bridge cannot carry the weight.” These limitation are used as ‘knock-out’ criteria and are applied separately before or after the cost considerations, in a serial, multistep process. Safety criteria are typically always implemented as knock-out criteria: people generally do not accept any safety risks, no matter what the costs are.
CBA and MCDA could be used to make these criteria part of the decision process itself. In the previous example: you could build a noise barrier on the bridge, if you consider reconstructing or supporting the bridge. If you know the costs of the bridge reconstruction, you can enter these in into the CBA. Examples also exist, for instance in German / Swiss legislation, where the costs are also a two-step process, with a basic consideration of cost proportionality first, following by a more extensive CBA analysis if the result is positive towards noise abatement measures.

MCDA in theory could be a very good solution for cost/benefit decisions, because it allows to include other criteria that are difficult to quantify otherwise. Also, MCDA can be tailored to the specific situation and the specific public environment. If used well, it may increase the acceptance and the increase public feeling of influence on their own noise situation. This feeling of influence as such also has a decreasing effect on the perceived annoyance (see [39]). MCDA is more suitable for a local project, if the project scale can justify the time and budget required for the public consultation and analysis.
Since, however, we have not been able to find any good, recent applications of MCDA methods for noise abatement, it is not regarded as ‘best practice’.

5.4.2 General recommendations

In any application of these methods, it is highly recommended to be clear and specific about the method, the outcome and the uncertainties. For any decision or study, a report should state the values used: cost-benefit decisions should include the willingness-to-pay, health costs or VSL values used. Cost-utility decisions should include (references to) dose-effect relations and values for the disability weights. For all methods, it should be clearly stated which items are included on the costs side (direct and indirect costs, maintenance, administrative costs, etc.). It is advisable to be clear and realistic about the accuracy of the outcome, especially in cost-benefit and cost-utility applications.

Good examples of applications of cost-effectiveness and cost-benefit systems exist in EU countries (e.g. UK, CH, NL, DK, DE). Member states and decision makers that want to develop or implement a system should consult their EU colleagues, possibly through EPA-IGNA, for experiences and advice.

6 Decision methods in practice

6.1 Introduction

The previous chapters 3 and 4 discussed the costs of abatement measures as well as the benefits: the reduction of external costs of traffic noise. Chapter 5 provides an overview of methods that are available to determine the appropriate balance between the costs and benefits for noise abatement measures.
The contents of these chapters come from extensive research of, mainly public, literature as well as from studies M+P has previously been involved in. As indicated in the beginning of this report, however, we are also interested in how decisions are actually made by the policy makers involved with traffic noise.

In this chapter we present various examples from decision making practice. We present examples as much as possibly on all topics presented in the previous chapters. We also want to present examples from many different European countries, in order to get a realistic overview of the actual decision making processes on any level, rather than base our conclusions on a few countries with detailed and sophisticated regulations. This is the primary reason to put out a survey through the Eionet network (http://www.eionet.europa.eu/), in which most of the European countries and states are involved.

6.2 Eionet survey

6.2.1 Survey description

A survey on *decision methods and cost/benefit for noise abatement measures* was put out as an online questionnaire through the Eionet forum. The survey consisted of 14 questions, some consisting of several parts, which address the following subjects:

- (national) budgets for noise abatement measures, and how to determine these;
- financial costs for noise abatement measures: What is included in the costs?
- quantification of benefits for noise abatement measures: What unit / method is used?
- monetarisation of benefits: is this applied? And if yes, what method and what values are used?
- other criteria that are included in, or influence, the decision making process
- good and bad examples of decision making for noise abatement
- personal opinions on current practice: How to improve?

The participants have been asked to indicate if their responses apply to road, rail and/or aircraft noise, and to indicate differences for the different modes if applicable. Participants have also been asked to indicate if their responses apply to improvement of existing high noise levels, to the reconstruction of existing infrastructure, to the construction of new infrastructure and/or other situations.

The full survey text and questions are given in Appendix A.

6.2.2 Response

Eionet is a network of environmental bodies and institutions active in the EEA member countries. It is made up of national focal points (NFPs); one in each country, national reference centres (NRCs) and European topic centres (ETCs). Currently, the Eionet has 33 member countries and 6 cooperating countries. The survey was sent out through the Eionet forum, which means that all Eionet members subscribed as NFPs and NRCs for noise have received an e-mail invitation to participate and fill in the questionnaire. Some have responded by e-mail.

The total response to the survey consists of:

- 19 responses in total;
- from 13 countries: Czech Republic, Iceland, Ireland, Denmark, Bulgaria, Poland, Switzerland, Kosovo, Sweden, Italy, Belgium (Wallonia), Finland and Malta:
  - with 2 reactions from Ireland: the national road and rail authority (TII) and the environmental protection agency;
  - with 4 reactions from Bulgaria: the national road authority (API) and the municipalities of Varna, Plovdiv and Burgas;
  - with 2 reactions from the Swiss Federal Office for the Environment: one for road noise and one for rail noise;
  - with 2 separate reactions from the Iceland member.

All 13 countries have indicated that their answers apply to road traffic noise. The responses for 7 also apply to rail traffic noise and for 4 countries (Italy, Iceland, Bulgaria, Finland) also apply to aircraft noise.

In addition to these 19 survey responses, some information was added by M+P from private communications with people from the noise community in Belgium (Flanders), Germany and the Netherlands. This brings the total count to 15 countries. Some public info was found for UK, which has also been added, but which is incomplete.

<u>Disclaimer</u>
In total, these responses present a wide spread over European countries as well as different levels of sophistication. We are happy with this response since they provide a wide reference for the results and conclusions. However, information from several larger and smaller countries (e.g. France, Spain, Portugal, Balkan countries and Baltic states) is not available. Other regulations and methods than presented here may exist, therefore, and some countries may have other policies or political opinions on the subject of noise abatement.

6.2.3 Results

<u>Cost/benefit methods in national legislation</u>
Questions 2A and 2B ask if national legislation contains any formalized cost/benefit method or, if not, if any common practice method exists.
Only Netherlands and Switzerland have official legislation for cost/benefit decisions for traffic noise abatement measures. Italy indicates that such legislation is currently in development. Eight other countries, however, indicate that they do have some common practice method that is used in different national or local noise abatement or infrastructure reconstruction projects.
The other countries have no legislation or common practice methods. This was formulated by Czech Republic, for instance, as “the intuitive approach prevails”. Some ‘rules-of-thumb’ may still exist, however: Belgium (Flanders), for instance, has a guideline for noise barriers that indicates that an extra 0.5 m height is only justified if the extra noise reduction is at least 1.0 dB(A).

Questions 3A and 3B ask to what situations this legislation applies (new infrastructure, reconstruction, noise sanitation, etc.) and if there are any differences in legislation between these situations.
Most countries (11 out of 15) indicate that their legislation applies to improvement (sanitation) of existing high noise levels as well as to new infrastructure and reconstruction of existing infrastructure. Two countries only apply legislation to new infrastructure and reconstructions. One country applies legislation for sanitation and reconstruction, but not to new infrastructure. One country applies legislation only to reconstruction. The Bulgaria NRA indicates that legislation also exists for monitoring of noise levels in specific public health areas.

Concluding, we discriminate three levels (stages) of legislation for cost/benefit considerations in national legislation:

- official legislation containing a well-described cost/benefit method that in principle is to be applied for all traffic noise abatement decisions;
- common practice methods that are generally or often used, in different infrastructure projects and/or for improvement of high noise levels. Jurisprudence for these methods may also exist, so they may form a legal requirement in a court of law;
- ad-hoc cost/benefit considerations may be part of specific projects, but there is no general or common method.

Legislation may be different for different situations, but these differences are limited:
- some countries indicate that the noise limits are different for new infrastructure than for reconstruction of existing infrastructure;
- in the case of reconstruction of existing infrastructure, there may be some additional rules or considerations when deciding whether or not it is justified to replace an existing noise measure; for instance, an existing noise barrier will only be replaced by a higher noise barrier if this leads to a minimum amount of extra noise reduction.

National budget
Questions 4A and 4B asked if there is a national budget set for traffic noise abatement and, if so, how the height of this budget has been determined.
Most countries have no national budget dedicated for noise abatement measures. That indicates that cost considerations for noise abatement measures may not be considered at all, or that they are performed within the scope of specific infrastructure projects: the budget for noise abatement measures is included in the total budget for the project, but is not limited by any budget on national scale.

Some countries, however, do have a budget allocated for noise abatement measures on a national scale. These budgets are determined for a specific period (one year, or up to five years ahead) and are in some cases linked to the END strategic noise maps and action plans.
In Switzerland and the Netherlands, a national budget is available for remediation or improvement of existing high noise levels along roads and railways. In Denmark, a national budget was available from 2009-2014 in their “Green Transport Policy” agreement.

Cost effectivity arguments
Questions 5 and 6 were about cost effectivity considerations in decisions for noise abatement measures. Question 5 asked how to determine if the noise reduction for a particular measure is enough to justify its costs. Question 6 asked to what extent the cost effectiveness of a noise abatement measure is accepted as an argument not to meet the legally required or desired noise limits.
With regards to the acceptance of low cost effectiveness as an argument not to meet the noise limits, there are basically three categories of answers given:
- Some countries do not have legal noise limits or specific target values. In that case, the costs for the noise abatement measure are an important, or even the main criterion for the decision.
- Some countries do have legal limits and cost effectiveness is not considered a valid argument to meet these limits. That means the noise abatement measures have to be taken, at all costs (in principle). Some indicate that this leads to requirements for expensive noise measures, such as high noise barriers.
- Some countries combine both: legal limits apply, but cost effectivity considerations are (legally) accepted as an argument not to take noise measures that are considered too expensive.

Methods to determine the level of acceptable costs differ as to how the method works (see below), but also with respect to their level of regulatory implementation (see above).

Costs, benefits and other criteria included in the considerations
As we have seen above, even though decision methods are not formalized in most countries, some consideration of costs and benefits is common for noise measures in most countries. The questions

7 to 10 focus more on the details of these cost considerations: what is included in the considerations and how are decisions made?

Figure 11 shows what people actually include in the costs for noise abatement measures. The graph only includes the results from the 19 direct survey responses; information for other countries from public sources does not include this level of detail.
Most indicate that the direct costs are included, which are the costs needed to put up the noise measure. We've separated the maintenance costs from the direct investment costs, and more than half of the respondents indicate that maintenance is included.
An example where direct costs are not included is the case where only passive noise measures are considered, which is a separate category in our list. Costs for passive noise measures, such as façade insulation, are considered by half of the respondents. Five respondents indicate property value compensation as a cost category, which may also be considered a passive noise measure (as is the case in Germany, for instance).
Administrative and legal costs are generally disregarded. The category 'time loss of speed limits' has a low score. This may indicate two things: (1) speed limits are not considered as a noise measure, or (2) limiting the maximum speed is considered as a noise measure without calculating the economic effect of the time loss. We have the impression that lowering the maximum speed only for the purpose of noise abatement is not a common measure, therefore we consider the first option to be more likely.

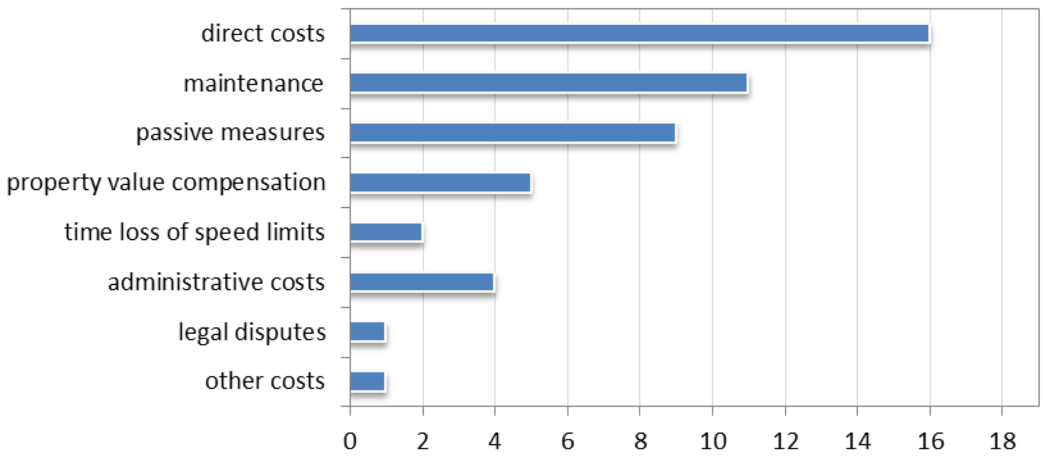

figure 11 *Cost categories included in the cost considerations. Only direct survey responses are included; the number indicates the amount of responses that included the cost category.*

As we have described in chapter 5, various decision methods differ mainly in what benefits are taken into account, and how these benefits are quantified. Question 8 presented the respondents with some different options. Figure 12 shows that most countries use decibels, so the noise reduction of the abatement measure, or the noise level after applying it. The dB may be multiplied by the number of people that benefit from the noise measure, or it may indicate the decrease in the total number of people exposed in various noise classes, for instance. A limited number of respondents have indicated other units for quantification of the benefits, among which monetary units or DALY's.

These are the units that people indicate when forced to choose. Although dB's may be the unit most commonly used in the national common decision making methods, studies into monetary or DALY units may still exist. As an answer to question 9, 5 out of 13 countries indicate that monetarisation of benefits is applied in their country. Public information shows that NL, UK and DE also have more or less standard values for monetarisation of noise benefits. So, even if it is not part of national common decision making, countries may still use monetarisation studies to investigate how high

external costs from environmental noise are and how much of these costs may be saved by investing in noise abatement measures.
We have also asked which values are used for monetarisation, but this question has not been answered by most. From public info or reports sent by the respondents, we were able to compare the WTP values used for road noise for NL [59], SE [58] and UK [60], as well as the 'EU-average' value proposed by the WG-HSEA. The results are given in figure 13. For the NL, SE and UK values, both annoyance and health costs are included. All prices have been converted to €, price level 2014.
It is clear from the results in figure 13 that the WTP values used are quite different, with a factor of 7 or 8 between the highest and lowest values. These large differences are confirmed by the investigations of the CEDR Road Noise group, as reported in [24].

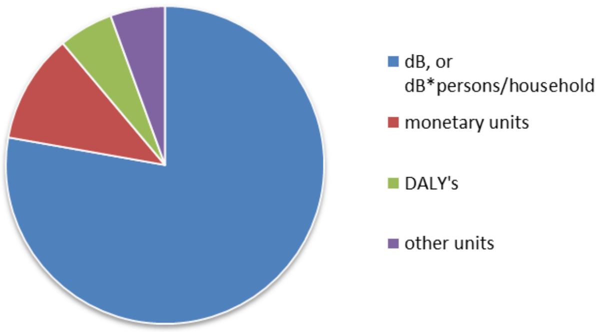

figure 12 *Units used for quantification of the benefits of noise measures*

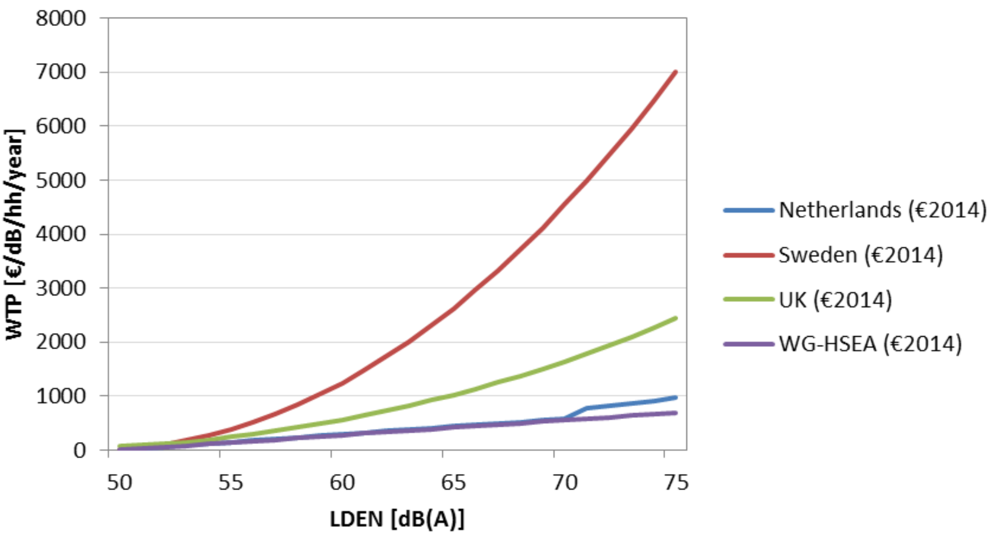

figure 13 *Examples of monetarisation values used in different countries; values indicate the WTP for the total noise costs (annoyance plus health costs)*

Besides costs and benefits, other criteria exist that may influence the decision process, such as safety and reliability, or socio-cultural and political issues. Question 10 is a multiple choice question asking which additional criteria are considered when making decisions on noise abatement measures.

Figure 14 shows the results of the survey responses to this question. About half the respondents indicate technical limitations and/or maintenance issues, and also half of the respondents indicate safety issues. This should not be interpreted as that there are no technical limitations, or that noise measures are taken that are not considered safe, but merely that these criteria are not part of the decision process: one simply does not consider any noise measures that are not safe and sound.

Aesthetic and socio-cultural considerations are also indicated by about half the respondents. That is: when deciding on a particular noise measure (e.g. a noise barrier), the decision makers often consider if the noise measure fits the landscape and is considered acceptable, by the public living around it and/or by the infrastructure users. Other criteria proposed, such as secondary benefits or innovation & research, are not often considered.
More details on these and other criteria that influence the decision process is given in Chapter 7 below.

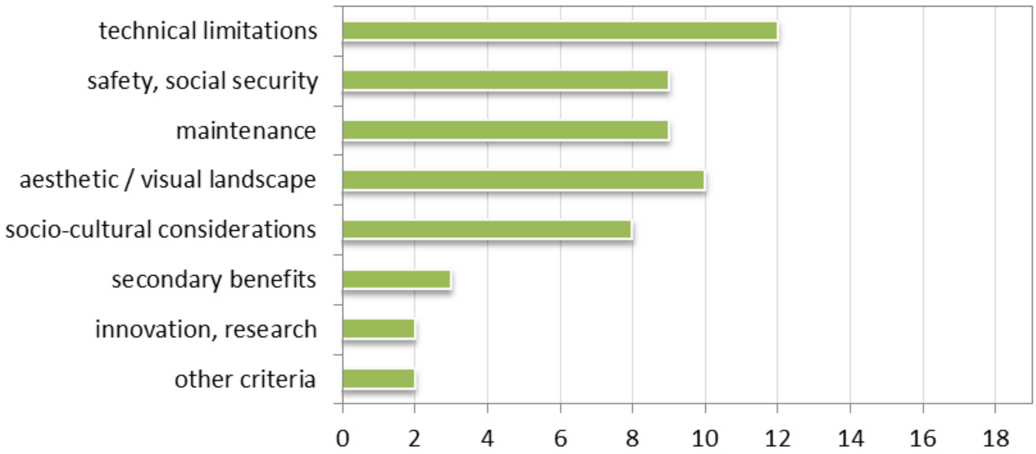

figure 14 *Other criteria considered in the decision process. Only direct survey responses are included; the number indicates the amount of responses that included the criterion.*

Methods used for cost considerations

In the previous section, several aspects and criteria for costs, benefits and other criteria have been identified and quantified. The actual methods used to balance these criteria are described only by some respondents, and only briefly. Some examples of national methods used for the decision making are described in paragraph 6.3 below.

Good and bad practice

Questions 11 and 12 ask for any good and bad examples of decision making for noise abatement measures. These questions have delivered only limited answers:

- The Swiss methods for cost/benefit decisions on road and rail noise abatement measures and their application for remediation of high noise levels are considered a success, also because of the transparent criteria. The WTI method (see 6.3.3) could be approved by a more clear definition of the project area perimeter. Also, stubborn application of the method may lead to unwanted outcome, e.g. many short noise barriers instead of one long one.
  This corresponds to experiences with the Dutch method. Some common sense from the acoustical engineers is always required to obtain plausible and acceptable results.
- Wallonia mentions the bad example where road managers decided to install timber barriers, which quickly degrade and therefore are not as cost-effective as they may seem.
- A good example mentioned form Plovdiv, Bulgaria, is the case of a new kindergarten built near a busy road, where many criteria, including aesthetic, visual criteria and technical limitations (limited space for noise barriers) were carefully considered.

Other examples mention projects where noise measures have been applied, but these do not go into good or bad aspects of the decision making process and methods.

The final questions 12 and 13 ask what is the personal opinion of the respondents on the current decision making methods in his or her country, and what could be improved. Summarizing the answers, suggestions focus on the following aspects:

- Several respondents indicate a lack of sufficient funds for noise measures. There is not enough budget available to effectively resolve traffic noise issues, other that the most extreme cases.

- Several respondents identify a need for a common cost/benefit method in their country. It is also suggested that such a method could be described or developed on EU level. Besides the method, the legal infrastructure, as well as noise limits in some countries, is lacking.
- Many indicate that the design and planning of noise abatement measures should happen much earlier in the project planning process. In many cases, noise is an 'afterthought' for which, at this late stage, insufficient time and budget remains. At an even earlier stage, better land planning may prevent traffic noise issues.
- Several respondents indicate a need for more education on environmental noise, as well as more and better dissemination of information on the adverse effects on public health, to the public as well as to the decision makers. This will increase awareness and give more attention to the problem.

6.3 Examples of application for noise abatement measures

In several countries the balancing of the costs for noise abatement measures and the social benefits on a project scale is mandatory. In the next paragraphs a few examples will be presented and discussed.

6.3.1 The Netherlands

Cost effectiveness legislation

For the Dutch national highway and railway networks, a mandatory calculation algorithm has been defined to assess the financial effectiveness ("doelmatigheid") of a noise abatement measure, or a combination of measures. The algorithm is used for new highways and railway tracks as well as for reconstruction of existing routes, to determine which of several sets of noise abatement measures is the most effective. It is up to the acoustic engineers in the project to come up with different sets of noise abatement measures. The financial effectiveness of a certain set is calculated as follows:

- identify, within the project boundaries, all noise-sensitive dwellings (houses, but also hospitals, schools, etc.) that are exposed to a noise level above a threshold (50 dB(A) for road traffic noise;
- for each dwelling, calculate the budget available for noise measures. The budget is a nonlinear function of the noise level at the façade. Rather than in Euro, the budget is expressed in 'points';

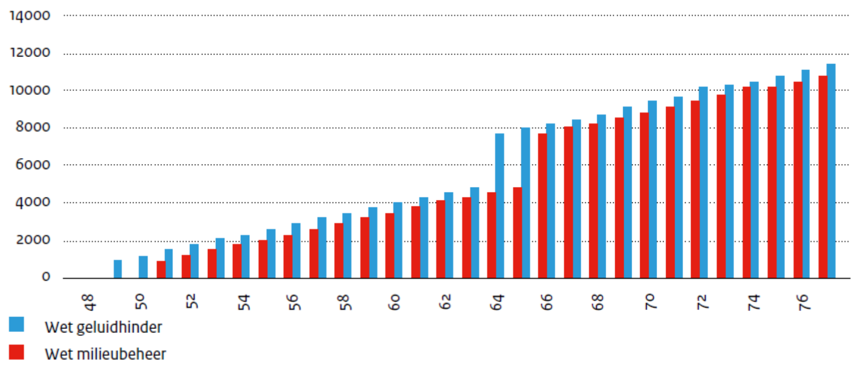

figure 15 Budget points for road traffic noise along national roads [40]; red bars are for the national road (highway) network; blue bars are for (sub)urban roads, for which older legislation (Wet geluidhinder) applies

- divide the dwellings in clusters, which are sets of adjacent dwellings. The clustering is prescribed, based on geographic locations of dwellings and the road/track;
- define different sets of noise mitigation measures for a cluster. For each set, calculate the costs. Standard cost estimates are given for low-noise road surfaces and noise barriers (roads) and for rail dampers, concrete slabs and noise barriers besides or between tracks (rail), as a function of

dimensions (height, width, length). Costs are based on life cycle costs (primary investment + 30 years of maintenance) and, just as for the available budget, expressed in 'points';
- for each set of noise mitigation measures, calculate the total noise reduction, as a sum of the noise reductions for each dwelling above the threshold;
- apply the following rules to select the appropriate set of noise measures:
  - if a certain set provides enough total noise reduction to bring all noise levels below the limit, then more expensive measures are not to be taken (Cost Minimisation);
  - if all available budget points have been spent on the designed noise measures, but not all limits have been fulfilled, then more expensive measures are not to be taken;
  - given a most effective set of noise measures from the first two rules: if a significantly cheaper alternative set is available with a total noise reduction that is nearly equal, than the cheaper alternative should be chosen (Cost Effectiveness). This may be the case for instance, if a noise barrier of 8 m is required to lower the noise levels at the top floor of a high apartment building, while a noise barrier of 5 m would be enough for all the other dwellings. This cost-effectiveness criterion is not quantified; it is left up to the project engineers to determine whether the additional noise reduction is worth the extra costs;
  - if the new set of noise measures requires that an existing (lower) noise barrier is demolished, but the existing barrier is younger than 10 years, it cannot be extended in height and the total noise reduction is nearly equal to the new barrier, than the existing noise barrier is to be retained. This rule is introduced to prevent destruction of capital.

The above description is for roads, but the rules for railways are similar. Other details apply that are not given here.

The Dutch algorithm should be considered as a Cost Effectiveness (CEA) method. It is more complex than Cost Minimisation, since it does regard the effectiveness of the noise measure with respect to a more expensive noise measure. It does express both costs and benefits in the same comparable units (although not direct monetary units), which makes it look like a CBA method. It does not, however, consider the extra social benefits *above* the legal requirements. Also, the benefit side has a fixed, undefined relation with the social benefits. It is not directly linked to public health, and it does not allow to include other benefits, even if they can be monetarised. It should, therefore, not be regarded as a CUA, CBA or MCDA method.

The Dutch legislation explicitly states several criteria that may obstruct the application of a noise abatement measure. These stated criteria include technical objections, traffic mobility objections and objections that arise from urban or landscape planning. The criteria are elaborated in more detail by the road and rail directors. For instance, porous road surfaces, even if cost effective, will not be applied in sharp corners or close to traffic lights, due to the quick deterioration. Cost effective noise barriers will not be applied if they hinder daylight for nearby housing, or they are replaced by transparent barriers. These criteria are not part of the cost effectiveness analysis as such, but serve as separate 'knock-out' criteria.

<u>Cost-benefit and monetarisation applications</u>
The Dutch National Institute for Public Health and the Environment (RIVM) has investigated the monetary benefits of road and rail noise [41] and aircraft noise around airports [42]. Their studies mainly contain the application of hedonic pricing for the different noise sources. They observe the effect of noise on house pricing and rents, and also include the effect of noise on (uninhabited) land prices. RIVM uses NDI values for road and rail that stem from Bateman et al. [43], which are 0.5% for road and 0.25% for railway traffic noise. The NDI value used for air traffic is 0.8%. The RIVM report points out that NDI values concern the total effect on house price over the whole of its lifetime, while WTP values are expressed per year.
The main goal of the RIVM report is to estimate the total economic loss of traffic noise in the Netherlands and to compare the effectiveness of different noise measures. Their conclusion is that the total economic loss, estimated from the total reduction of house and land pricing, due to traffic noise amounts to 10.8 billion Euro, of which 9.6 billion is due to road traffic noise. They estimate

that 65%, or 7 billion Euro, could be reclaimed by cost-effective noise measures. Further benefits would require noise measures that are too expensive (such as high noise barriers).
The RIVM report is a good example of a cost-benefit analysis, applied on a national scale. These kinds of national policy studies are really the domain of CBA.

A different Dutch study specifically for aircraft noise [51] in the agglomeration around Amsterdam Airport resulted in a total benefit per household of a 1 dB reduction of € 1500,- which is reported to be equivalent to a marginal benefit of 75€/dB/household/year. These values are, as expected, higher than the data found for road and rail for the RIVM study. Compared to the WG HSEA 2001 value of 25€/dB/hh/yr, the value for aircraft noise in this study is three times higher.

6.3.2 Belgium (Flanders)

The Flemish road traffic agency has provided information about their decision making methods for road traffic noise abatement measures. Currently, no cost-effectiveness or cost-benefit methods have been prescribed in legislation. Since 2011, there is a standard flowchart used to judge the effectivity of noise barriers. It is mainly based on the effectivity of the noise barrier in dB, with respect to the limit values and the required insertion loss. It does state additionally that increasing the noise barrier with 0.5 is only cost-effective if the noise reduction is lowered by at least 1 dB(A). No such criterion exists for other noise mitigation measures. There is no further, general legislation for other criteria (such as aesthetics, safety, etc.); these decisions are evaluated for each situation separately.

6.3.3 Switzerland

Cost benefit legislation
In Switzerland, the Federal Office for the Environment (FOEN)) provides guidelines to judge the cost effectiveness and the appropriateness for noise abatement measures. The guidelines prescribe the optimal balance between the effectivity of a particular set of noise measures, and the *efficiency* (cost/benefit ratio) of the noise measured:

- The *effectivity* of the noise measures is expressed as the total noise reduction at all dwelling facades, as a percentage of the total noise reduction needed to bring all noise levels down to the target values: 100% effectivity means the noise immission at all dwellings is below the limits.
- The *efficiency* is expressed as the ratio between the total benefits of the noise measures and the total costs. Monetarisation of the benefits is done based on a hedonic pricing method, which is to be applied for each particular location; no predefined values exist. The costs are life cycle costs, including investment and 40 years of maintenance. Standard cost estimates are given for low-noise pavement, noise barriers and noise insulation measures at the dwellings.

From the effectivity and the efficiency, the WT-index is calculated:

$$WTI = effectivity * efficiency/25.$$

Five WTI classes are then used to determine the economic acceptability of the noise measures, see figure 16.

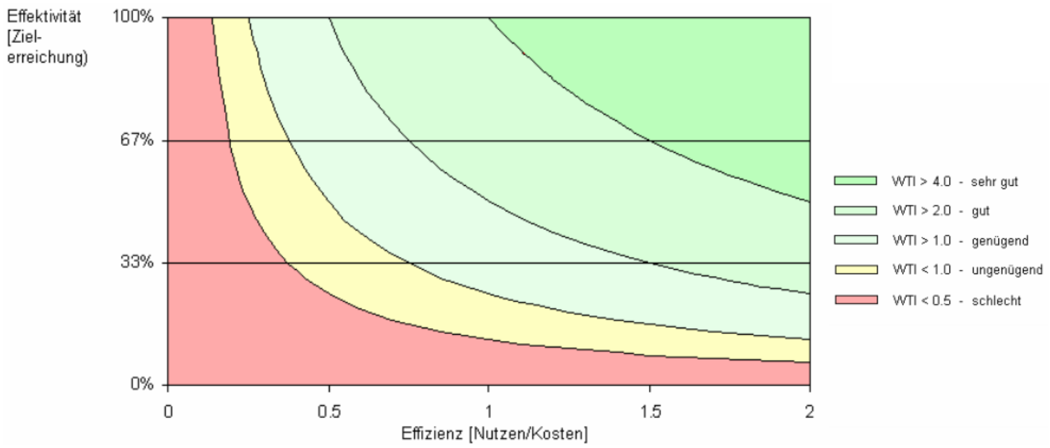

figure 16 *Effectivity vs. Cost/Benefit efficiency diagram, used in Swiss legislation to determine the economic acceptability and appropriateness of noise abatement measures; colours indicate the "Wirtschaftlichen Tragbarheitsindex" (WTI), a measure for the economic acceptability ranging from very good (green) to bad (red).*

Monetization of health impacts

An interesting Swiss study [47] addresses the differences between different methods for monetarisation of the health impacts due to traffic noise, and the results when applied to the Swiss situation. The report discusses why and how monetarisation of traffic noise should be (or should not be) done. The methodological difficulties for different cost-benefit and monetization methods are discussed, as well as the difficulties in comparing results from different studies and methods.

The report follows the main approach of estimating the effect of noise on health in HALY (cost-utility), then monetarizing the HALY using the value of a statistical life (VSL) or the value of a life year (VOLY). The health effect, in this report, is confined to sleep disturbance during the night and interference with communication during the day. Multiple methods have been pursued to estimate the VSL. One method estimates the health impairment in DALY, using estimations of sleep disturbance and interference with communication from the noise levels. The DALY's are calculated with the disability weights for these two effects, and then related the average reduction in apartment rents as a result of this health impairment. This method gives the lowest value for the monetary equivalent of 1 DALY: 42.727 CHF (inflation level 1996). The second method estimates the VSL by comparing WTP values found in stated preferences studies for the prevention of other diseases, both temporary illnesses and chronic diseases. The third method uses monetary limit values from medical practice (drug and therapy research). A fourth method uses VSL values from wage risk studies (the relation between workplace risks and income earned). Two last methods contain new research on the amount of money people actually pay for a health improvement: plastic surgery and some medical therapies. These last methods provide the highest values: approximately 250.000 CHF as a monetary equivalent of 1 DALY.

The Swiss study gives a good overview of CEA and CUA vs. CBA methods, various monetization methods, and difficulties and results from existing studies. The monetization part focusses on monetarizing the health impairment in DALY and is therefore a combination of cost-utility and cost-benefit methods, according to our definitions in 4.

Cost effectiveness for rail noise abatement measures

The cost benefit index (CBI, or the WTI as explained above) is an important factor in the application of noise mitigation measures in Switzerland. Therefore, the CB ratio was studied for rail noise measures in the Swiss territory. For the total network about 70 scenarios were calculated. Results are in line with other studies mentioned in section 3.3. Retrofitting K- and LL-blocks gave better benefits per costs ratio's than only barriers. An important issue in the Swiss study was that retrofitting only Swiss stock was only slightly better than application of noise barriers only below a certain CBI. This is explained by the vast number of non-Swiss stock on the transit corridors. Including all stock gave a major improvement for the Cost Benefit ratio. The addition of barriers with a maximal CBI resulted in only a slightly lower benefit/cost ratio (see figure 17).

The comparison between different noise measures given in figure 17 is an example of a cost-effectiveness analysis for rail noise measures (CEA), as indicated by the author on the vertical axis. The total noise reduction (in persons x dB) is the only output parameter, and the different noise measures are compared to give the noise reduction that is optimal with regards to the costs.

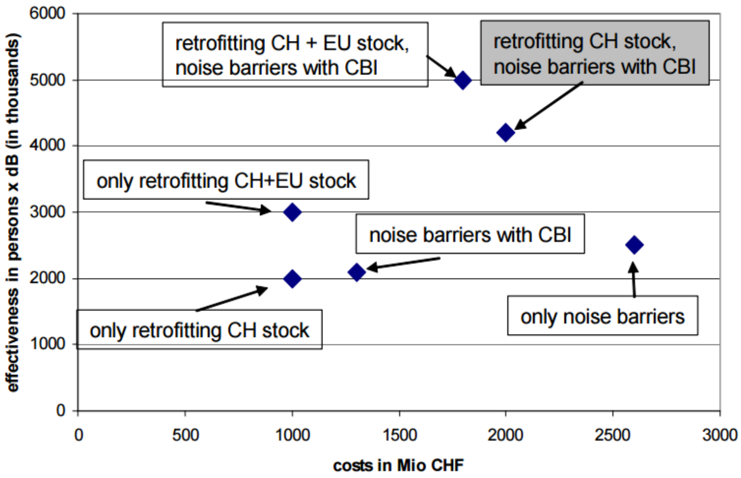

figure 17 *Costs and benefits of retrofitting freight wagons compared to application of barriers (source J. Örtli [18])*

Multi-design criteria analysis for track optimisation (noise, vibrations, maintenance)
The Swiss railway director SBB is currently running the “Go-Leise” project. The project focusses on optimisation of the railway track as a whole, including all components of the track system (rail, ballast, sleepers, dampers, fastening, etc.). The optimisation aims to optimise not only for noise, but also vibrations, safety and infrastructure life-cycle costs, since these parameters may contradict each other. The method incorporates costs and maintenance, but also noise in the management and decision making for Swiss railway assets.

The project uses an “LCC” approach to find the optimal solution, which means that the LCC includes costs for procurement, operation, maintenance, non-availability and the social economic costs (energy consumption, environmental impact, delays etc.). The actual decision analysis method chosen for the optimisation is still to be decided, however, and may differ for different areas of application. The project considers both CBA and MDCA as an analysis tool and has compared advantages and disadvantages [19]. The decision for one method or the other will be made later in the project.

6.3.4 Germany

Cost benefit legislation
German legislation only describes the cost effectiveness of noise abatement measures in qualitative terms. Therefore, in addition to official German legislation, the LFU Bayern have published a report that describes the decision process for road and rail noise abatement measures. This report has been referred to in court and is now part of the German national jurisprudence. The flowchart in figure 18 describes this decision process. If the noise limits are exceeded, the first step is to assess if the costs for noise abatement measures are reasonable. If the costs are not clearly justified, then the LFU proposes to assess the cost effectiveness using the noise cost function given in figure 19. The noise costs per person per year are a function of the amount of dB’s exceeding the limit (L_{den} or L_{night}). These noise costs are an approximation of the values found from hedonic pricing

studies in Germany. The NDI found from the hedonic pricing study [46] were 1.5%, which is much higher than other values found for road and railway noise in the Netherlands (see 6.3.1) and in the US (see 6.3.7).

Former German legislation was based on a 4 : 1 ratio between the costs of 'active' vs. 'passive' noise abatement measures. Active noise abatement measures include noise barriers, rail dampers, low-noise surfaces, etc., whereas passive noise abatement includes building insulation, financial compensation and the governmental acquisition and demolishing of dwellings.

Also interesting in the flowchart of figure 18 is that other criteria, such as the impact on the visual landscape or technical limitations (e.g. bridge constructions) are explicitly included in one and the same decision process flowchart. In most other countries, these criteria are described elsewhere, in separate legislation or technical documents. These criteria may then be applied at a different moment, by a different party, leading to suboptimisation and delay in the decision process.

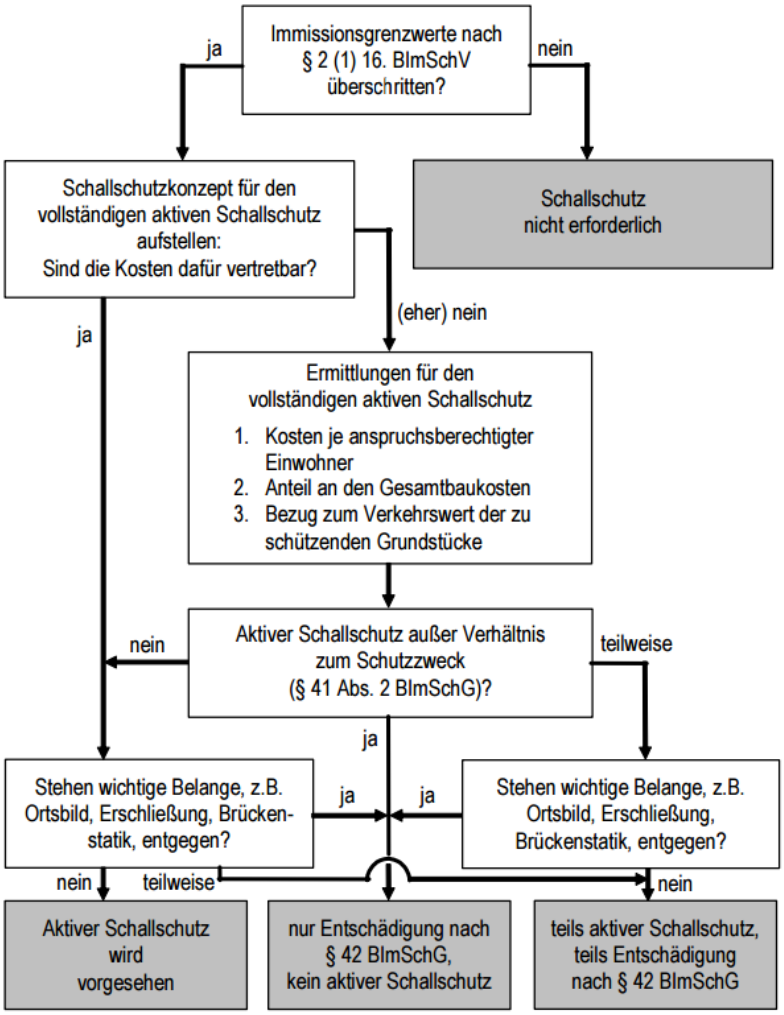

figure 18 *Flowchart of the decision process for road and rail noise abatement measures in Germany [45]*

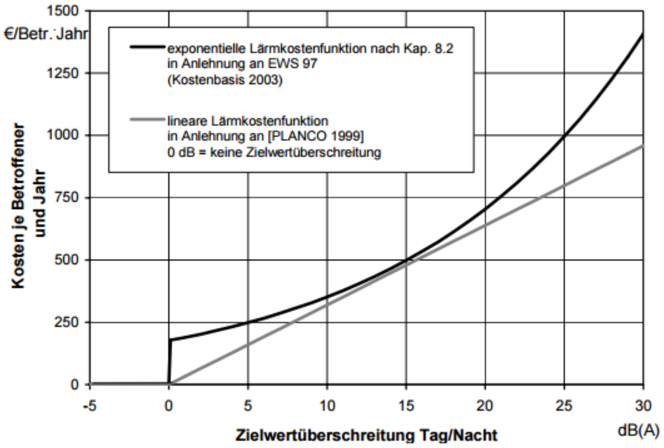

figure 19 *Noise costs per person per year as a function of the exceeded noise level in dB (equal for day and night) [45]*

6.3.5 United Kingdom

In the UK, the Department for Environment, Food and Rural Affairs (DEFRA) provide guidance with respect to the valuation of traffic noise[7]. Their guidance includes the Transport noise modelling tool, which is an extensive Excel sheet that allows to calculate the external noise costs for road, rail and aircraft traffic as a function of L_{den} and L_{night} values.

Their tool uses dose-effect relations for sleep disturbance, annoyance, Acute Myocardial Infarction (AMI) and hypertension, which mainly stem from the work of Babisch [54] and Van Kempen [55]. The monetary values are calculated by calculating the health effect in QALY's and then multiplying by a monetary value for each life year (VOLY). In the tool, the user is able to select different dose-effect relations (e.g. "high", "medium" or "low" estimates of sleep disturbance, annoyance, …) as well as difference disability weights (high/medium/low) for each health endpoint. Also, the user may select different values for the VOLY, ranging from £30.000 to £80.000. This allows the user to perform a sensitivity analysis.

A typical result of the tool is given in figure 20. Values are presented as "Marginal Values", expressed in £/dB/household/year. In our definitions in section 4.3 we consider these values 'average', as 'marginal' values would be expressed in dB per vehicle or kilometre.

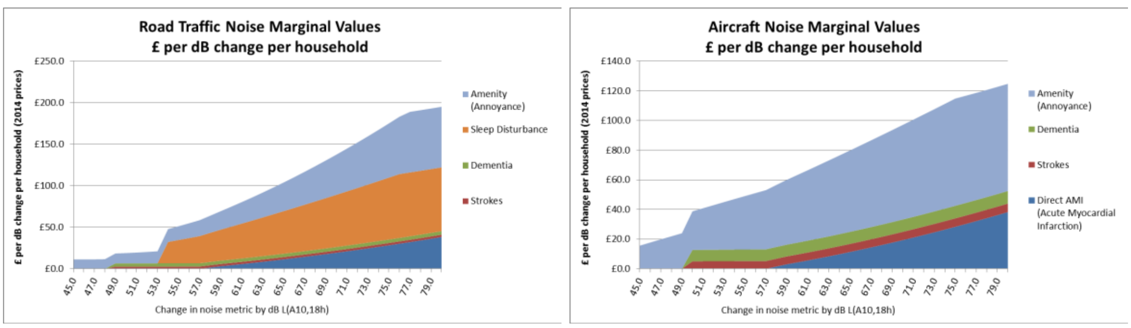

figure 20 *External noise costs per person per year in UK for road noise (left) and aircraft noise (right); values for railway noise are available, but not depicted here*

[7] see https://www.gov.uk/guidance/noise-pollution-economic-analysis

6.3.6 Europe

Several European projects have been conducted within the EU 5th, 6th and 7th Framework Programmes that aim at, or include, cost/benefit analysis and monetarisation for traffic noise. Three important projects have been:

- UNITE (UNIfication of accounts and marginal costs for Transport Efficiency), EU 5th Framework programme, appr. 1999-2002, which aimed at fair and efficient pricing of transport infrastructure use, taking into account the full social costs and benefits of transport; UNITE established estimates for external transport costs, including noise;
- HEATCO (Developing Harmonised European Approaches for Transport Costing and Project Assessment), EU 6th Framework programme, 2004-2006, which aimed at the development of tools, indicators and operational parameters for assessing sustainable transport and energy systems performance (economic, environmental and social);
- HOSANNA (HOlistic and Sustainable Abatement of Noise by optimised combinations of Natural and Artificial means), EU 7th Framework programme, 2009-2012, which aimed at developing a toolbox for the reduction of road and rail traffic noise in the outdoor environment, which is cost effective and shows positive effects on the environment as a whole.

<u>HEATCO project</u>

The HEATCO project partially built on the results of the earlier UNITE project. The HEATCO project output describes how road, rail, air and sea/waterway transport projects should be assessed [27]. Reviewed and proposed assessment strategies include value of time and congestion, accident risks, environmental costs (air pollution, noise, global warming), infrastructure investments and general issues, such as valuation techniques, monetarisation, decision criteria, etc.
Deliverable 5 of HEATCO [29], with annexes, provides, among other outputs, WTP values for road, rail and aircraft noise. The WTP values are given for 26 European countries as a function of noise levels, as well as European averages. Three different sets of values are provided: the ‘central’ values correspond to the values found by the WG HSEA [35], the ‘high’ values stem from Hedonic pricing studies as applied in the UNITE project [30] and the ‘new approach’ values contain data from a Stated Preferences study performed within the HEATCO project itself [28].
Values from the HEATCO project are widely used in following studies as reference or fall-back values for monetarisation of traffic noise.

<u>HOSANNA project: cost/benefit framework</u>

The HOSANNA project (http://www.greener-cities.eu) mainly focused on research and application of methods and measures to reduce transport noise. Innovative noise measures included mainly green noise barriers, vegetation (trees and hedges), and ground preparations. Work Package 7 of the project has developed an “open source” CBA framework, with web-based input forms, to be applied for assessment of traffic noise abatement measures. The framework is described in several deliverables that can be found on the project’s website; a website that actually provides an online CBA framework could not be found.
An interesting result from the HOSANNA project is that they were able to establish monetary values for aesthetic properties, in their case applied to urban greenery [56]. They estimate the WTP for vegetated walls or roofs to be 2.4 €/person/year per m^2 wall or roof (2010 price level).

<u>CEDR State-of-the-Art report 2017: cost-benefit and cost-effectiveness analysis</u>

The need for good and objective methods to balance the costs of noise measures with the external cost of environmental noise has also been identified by the European National Road Authorities. The Conference of European Directors of Roads (CEDR) has issued a State-of-the-Art report on CBA and CEA methods for road noise, which was published in January 2017 [24] and presented in the CEDR symposium on road traffic noise management and abatement, May 2017 in Copenhagen.
The CEDR report corroborates the findings in this current EPA-IGNA study. Their main conclusions are:

- CBA and CEA are useful tools to make objective and verifiable investment decisions for noise abatement measures, along existing roads as well as in the planning and construction of new roads;
- CBA takes a more holistic approach than CEA by expanding the scope of analysis to all impacts of a measure or project. CBA is more demanding than CEA, because all relevant effects need to be assigned a monetary value;
- unit costs (€/household/year) used in different EU countries vary enormously, see figure 21, and values at higher noise levels are much higher than the recommended EU value [35]. Discussion on this subject with NL, DK, SE, UK and other experts during the CEDR symposium did not reveal clear answers to why these differences are so large;
- CEA is a simple but effective instrument for evaluating and prioritising noise abatement projects, as demonstrated by several examples in the CEDR report.

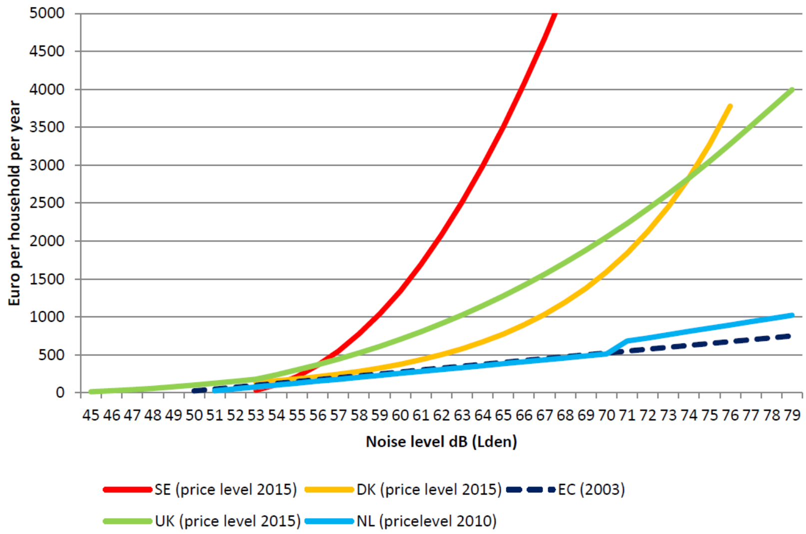

figure 21 *Unit cost for road noise for four different countries and the recommended EC value from WGHSEA 2003 (from [24])*

The CEDR report acknowledges the following focus areas as being important for future improvements for application of CBA and CEA:
- achieving better knowledge of the costs factors for road traffic noise by adding this issue to future CEDR research topics;
- investing in the dissemination of knowledge of using cost-benefit analysis and cost-effectiveness analysis for more effective noise abatement, by organising a workshop about the use of CBA and CEA in NRAs' practice.

6.3.7 US / international

Monetarisation of aircraft noise

CAEP, 8th meeting, has issued a report on the cost-benefit analysis NOx stringency of air traffic. Since some strategies for NOx reduction in engines compromises the noise emission, also the costs of noise are taken into account. In this report an income related value for WTP is used, based on the work that was published later in [50]. The data presented in figure 19 distinguishes between USA and non-USA situations. The WTP refers to an improvement that brings the value from above the significance level of 65 dB(A) Lden (or DNL) to a background level of about 55 dB(A). WTP values were based on hedonic pricing studies by others between 1970 and 2007.

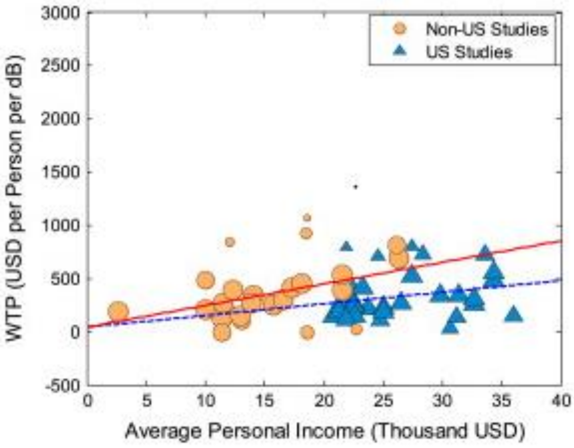

figure 22 *Yearly willingness to pay for aircraft noise reduction as a function of income per capita based on 60 hedonic studies of housing price depreciation [50], price level 2000*

The WTP value found for aircraft noise from figure 22 is given by

$$\mathrm{WTP} = 0.0138 * \mathrm{Income} + 0.0154 * \mathrm{Income} * \mathrm{NonUS} - 30.3440,$$

in US dollars (price level 2000), where the value for *NonUS* equals 1 for non-US countries and 0 for US countries.

In [52], WTP values from 15 different European and Japanese studies have been collected and compared. Figure 23 shows that values are quite different between studies. Table XV shows the mean NDI and WTP values. The international average WTP value of 56 €/dB/hh/yr value is higher than the 2001 WG HSEA value of 25€/dB/hh/yr for road noise, and slightly lower than the value found in The Netherlands (see 6.3.1).

The NDI values are also somewhat lower than Dutch values used by RIVM [42].

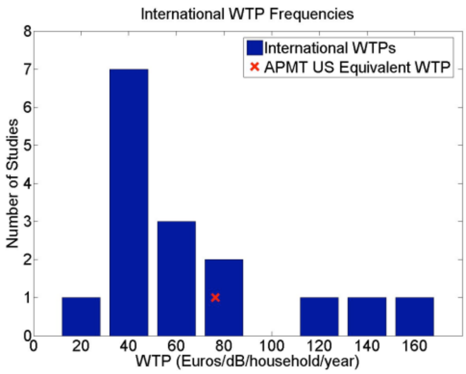

figure 23 *Distribution of WTP values found in international studies; red cross shows US value for APMT*

table XV *International and US values for NDI and WTP (from [52])*

	International values	APMT US Value
Mean NDI	0.59%	0.66%
Mean WTP (€/dB/hh/yr)	56	76

A case study for Chicago O'Hare airport included the WTP for annoyance by applying hedonic pricing, but also included the health costs for hypertension, based on an estimation of the number of cases times the costs for screening and drug treatment, and the health costs from damages learning abilities for children, from an estimated loss in future salary. The estimations from this study, for 50.000 households over a period of 10 years, including a 3% yearly discount, were:

- 5.3 billion dollars for annoyance;
- 383 million dollars for hypertension;
- 769 million dollars for children's learning ability damages.

The health costs included in this case thus amount to slightly over 20% of the annoyance costs. Unconscious sleep disturbance and resulting productivity loss seem not to be included.

6.4 Conclusions on decision methods in practice

In 6.2, we have presented the results of our survey, that aimed to gain more insight in the practical application of cost/benefit decisions around Europe. This survey provided good information about how decisions for noise abatement measures are made, which criteria are involved an what methods, if any, are used to balance these criteria. Paragraph 6.3 provided a series of examples of existing methods in national legislation and other projects and studies.

Summarizing the application of cost/benefit decisions in practice, we find the following

- <u>Costs</u> are always an important criterion for noise abatement measures.
  - Differences exist in what costs are actually included when calculating the costs for noise measures: maintenance costs are often included, but not always, and costs for passive noise measures are not always calculated.
- <u>Benefits</u> are usually expressed in the amount of noise reduction in dB, often combined with the number of people that benefit from the measure.
  - <u>Monetarisation</u> is common: about half of the EU countries have national methods and/or studies that include Willingness-To-Pay values for annoyance and health costs. The differences between values are large: a factor of 7 to 8 between highest and lowest values was found.
  - Other units also exist: some refer to DALY's, but others use their own scores or scales to quantify benefits.
- <u>Other</u> criteria are also considered. These are mainly safety and reliability issues, technical limitations or maintenance. Considerations on the impact on the visual landscape, or socio-cultural appropriateness, are also often included in decisions for noise measures.

We find large differences in the levels or stages at which these cost/benefit decision methods are implemented in national legislation.

- Some countries have sophisticated and well-defined regulations, including prescribed calculations for cost/benefit requirements: noise measures that are not cost-effective according to these rules are not to be taken.
- Other countries do have 'common' methods that are used throughout several projects, but these are merely to help the acoustic engineers in judging the appropriateness of noise measure costs, and have no legal status.
- There are also countries that have no cost/benefit methods and leave it up to the engineers and local policy makers to make these decisions on an ad-hoc basis.

The budgets available for noise abatement measure also differ largely between countries. For countries that are able to spend money on noise abatement measures often, a well-defined system for decision making is more important to guarantee an equal and fair distribution of the available budget over projects and problem areas. Countries with small budgets focus on the most extreme cases only and often need no additional method to identify or rank these. The END noise action plans are a common starting point for noise abatement policy decisions.

7 Other decision criteria

In the previous chapters 2 and 3, we addressed the two main elements in the decision for noise abatement measures being:

- The positive effect on public health and annoyance (chapter 2) that are the primary objectives for the noise abatement measure (although in an actual decision process for a particular situation, the goal may be to obtain a certain noise reduction (in dB) instead of assessing the actual effect on public health).

- The financial consequences (chapter 3) in terms of direct and indirect costs.

There are however other criteria that may also influence the decision for applying and selecting noise abatement measures. In this chapter, we summarize some of these “other” criteria that lie outside the direct scope of the balancing of costs and benefits, but are essential in the final decision.

7.1.1 Technical limitations

In some cases noise abatement measures, that are available and have been applied on other locations, are not technically possible or feasible.

For instance, the load bearing capacity of some (older) bridges may be insufficient to carry a noise barrier, or a thick noise-reducing pavement. One could argue that this is not a limitation, since the bridge could be replaced by a new bridge that can carry the noise measure. But in most cases, this will be considered a no-go. Too little space between the road and the surrounding buildings, or piping in the ground, may also be an objection against placement of a noise barrier.

7.1.2 Safety

A noise abatement measure may lead to safety issues, which may be so severe that the measure is considered unacceptable.

One may think of low-noise tyres with unacceptable wet grip performance, or rail dampers that have turned out to come apart from the rail. But these noise measures will then be considered as unacceptable in general and will no longer be a part of the decision process.
More interesting for decision making are noise measures that lead to safety issues only in specific circumstances. A noise barrier may be considered a safety hazard in placed with high wind speeds, for instance, such as on top of a bridge. Or, a noise barrier may not be placed along some rail section because there are no exit routes available in case of a traffic accident. In the Netherlands, porous road surfaces are not applied in tunnels, because in case of fuel leakage the risk of fire is considered unacceptable.
Also, the balance between safety and capacity / mobility is a subject of decision making. Higher speed limits increase the risk or the severity of traffic accidents. Increased capacity for airports also leads to a higher accident risk. Still, the desire for more capacity and decreased travelling times may justify a decrease in safety, at least to some limited extent

7.1.3 Reliability, maintainability and availability

Noise abatement measures may have a negative impact on the reliability of the infrastructure. The rail track or the road surface, or the train, car or airplane, may experience a shorter time-between-failure because of the noise measure. This leads to increased maintenance costs, already covered in chapter 3. But it will also lead to a lower availability of the network and more traffic jams, due to more construction work, or complete unavailability of the network or vehicles in case something breaks down.

Also, the noise abatement measure may make maintenance more difficult or impossible. For instance, if rail dampers are installed the rail itself is no longer visible, which makes visual or automated inspection for rail defects more difficult.

7.1.4 Effects on mobility and capacity

The noise generated by the traffic may also be reduced by influencing the traffic itself. Lowering the vehicle speed for trains and cars will reduce noise. Changing the flight path for arrival and departure routes may reduce aircraft noise in urban areas. Reducing the number of trains and planes will reduce noise also.

Not all of these measures are actually considered for noise abatement, because they will affect mobility in a negative sense: it will take people more time, or it will make it more difficult, to get from A to B. The actual time delay may be quite small: for a road section of 10 km, lowering the vehicle speed from 120 to 100 km/h increases the travelling time by just one minute. However, if the road section carries 100.000 passages each day, the total economic impact of the time loss will be millions of Euros per year.
For environmental noise, the train of thought is generally the other way around: all the other noise abatement measures are considered, in order to maximize the mobility within the environmental noise limits.

It is argumented that changes in travelling time will only have an economic impact for a limited time: in the longer term, people will adapt their travelled distance, for instance by moving closer to or further from work. This may then, however, affect the house prices, which is also an economic impact. These arguments should be carefully considered when assigning monetary equivalents to travelling time units.

7.1.5 Social, cultural and aesthetic criteria

Some noise abatement measures are clearly visible and may therefore disrupt, or enhance, the visual surroundings. Noise barriers are the most obvious example. A noise barrier may take away the view from the houses nearby. This may be considered negative if it was a nice view, but is could also be a benefit if the visual separation from the highway enhances the feeling of safety and rural comfort. The same criteria are considered from the road or track side: the traveller likes to watch the beautiful environment without being hindered by a noise barrier. Or, on the benefit side, some well-designed noise barriers may be considered visually attractive.
One can also imagine a characteristic street in an old city centre, where the cobble stones or paving stones are an essential part of the ambiance, and should not be replaced by a more silent porous asphalt surface.

These kinds of criteria often do not lead to no noise measure being applied, but it may lead to a different type of noise measure, or the same noise measure in a different shape or material. These criteria contribute to the general preference of source measures (silent roads, silent track, silent vehicles) over noise barriers. Or, if that is not possible, transparent noise barriers are applied, or they may be covered with vegetation.

7.1.6 Politics and public acceptance

The decisions made by policy makers with regards to noise abatement measures will be influenced by public opinion and political considerations. Political arguments are not always based on objective information about health, annoyance and other quantifiable parameters, but may include some more irrational arguments that leads to certain measures being more or less popular.

Measures such as reducing traffic speed, banning old-timers / antique vehicles from the roads, or extra charges for vehicles without particulate filters, may be considered unacceptable because of a 'breach of public liberty', or some comparable argument.

Politics change over time and with location, as does the public opinion. People living in the city are generally willing to accept higher noise levels, whereas people living more remote may be more annoyed. It was shown recently by the Danish Road Directorate, for instance, that persons living near motorways are much more annoyed at the same noise exposure than persons living near urban roads [57]. Several arguments were put forward to explain this: age differences between country and city inhabitants, the ratio of indoor vs. outdoor annoyance, but also the fact that houses near motorways are more often privately owned, whereas people in the city more often live in rented apartments.

7.1.7 Research and innovation

New noise abatement measures, or optimised versions of existing measures, are continuously developed. These new noise measures need to be tested in practice. The first tests may be conducted on some smaller test location. Such testing needs will usually not influence the decision making process for noise measures. To get the innovative noise measure from a small-scale test to implementation and large-scale application, however, will require that it is applied on more locations and monitored over longer periods of time. The use of innovative noise measures may be stimulated by financial instruments (grants, stimulation funds) or by promotion of innovative measures in procurement and tendering. These factors may therefore influence the decision process.

7.1.8 Added benefits

Some noise abatement measures actually have another primary purpose or some secondary benefit. Or, the noise abatement measure may be specifically designed or adapted for an additional purpose.

Porous road surfaces originated primarily not because of their noise reduction, but because of their water permeability, aiming to reduce storm water runoff and splash/spray. This will still be a part of the decision to apply a porous road surface, although low-noise porous surfaces are now also applied purely on the need for noise reduction.

Noise barriers may also reduce particulate matter concentrations from road traffic for the residents nearby, which is an added benefit without an additional effort. But examples of added functions are also plenty. Noise barriers may also be integrated with safety barriers. Some noise screens are combined with solar panels to generate electrical power, which will also generate a financial benefit. Some examples exist, for instance in the Netherlands, where wide noise barriers are designed as a commercial building, giving room to a high-end car dealer on a high-profile location, and an entire shopping mall.

Measures that affect the noise may also be taken for largely or entirely different purposes. In decision making for measures that influence the traffic volume or the modal split between road, rail and air traffic, noise may be a very small factor. In these cases, it may be difficult to determine to what extent the costs can be attributed to a change in noise exposure. The methods described in this report, however, are still useful and could be included in an assessment of the total environmental and economic impact.

8 Conclusions and recommendations

8.1 Conclusions

Decisions for traffic noise abatement measures are very often based on the balance of the costs against the benefits. At the cost side direct financial costs for investment and maintenance are always included but other cost effects can be added. The benefit side may contain quite a range of different topics and criteria, but may also be restricted to one, or neglected altogether.

In many local cases, the maximum noise levels or the minimum noise reduction are fixed in national or local legislation, but as we have seen from the survey, there are also countries without noise limits.
In a situation with noise limits, the decision to take any noise abatement measures, as well as the choice for a particular noise abatement measure, may be as simple as choosing the cheapest alternative that complies with the legislation (cost minimisation), although some judgement of costs versus effectiveness is common (CEA). For more advanced noise policy making, the CUA method is commonly used to assess the actual effectiveness of the noise abatement measures on public health (in DALY) instead of optimizing the physical noise reduction in dB. The application of CUA in infrastructure projects or in (national) noise remediation programmes is not common, however.
For a more complete, integral balance between the financial costs and all the external benefits for society, two alternatives exist: MCDA or CBA.

Multi-design criteria analysis (MCDA) enables the integration of, in principle, any criterion, as long as it can be ranked or rated on some arbitrary scale. MCDA always requires the involvement of expert judgment and/or the enquiry of opinions from the public, so it cannot be performed as an anonymous desk study. The public involvement may be a good thing to increase acceptance and reduce annoyance, but it decreases the applicability of MCDA mainly to a project scale and makes it less suitable for national policy development.

The cost-benefit analysis (CBA) uses monetary units for both the cost and the benefit side, which is both its strength and its weakness. Using monetary units enables a direct comparison between costs and benefits: it is directly clear from the results if the budget for noise abatement measures exceeds the economic benefits. For policy making, where justification of the cost level set for noise abatement is needed, CBA may in fact be the only option. The main problem with CBA is that monetarisation is quite difficult and inaccurate for annoyance and health impacts. WTP values found from different studies show differences of several orders of magnitude, up to a factor 100 for aircraft noise from CV studies. Other criteria, such as aesthetic and socio-cultural aspects, are even more difficult to monetarise, at least on a large scale. But these criteria may only be applicable for local projects anyway, so for general policy making, this may not be a problem. Clearly, it comes down to selecting the right method for the question at hand.

In CBA, we have distinguished the top-down approach, leading to average noise costs (per dB, or divided in dB classes), and the bottom-up approach, leading to marginal noise costs (costs per extra vehicle, or vehicle kilometre). Marginal noise costs give more possibilities for fine-tuning to the traffic intensity, day/night time, vehicle speed, etcetera. But the results are less useful for internalization of costs, since the logarithmic nature of noise would make it cheaper to drive on a busy (noisy) road. Examples of practical applications of marginal noise costs in CBA are rare.

As far as monetarisation for CBA is concerned, many studies for traffic noise employ hedonic pricing by observing the relations between noise levels and prices of houses and apartment rents; in some cases, unoccupied land prices are also included. The general assumption in literature is that people are unaware of the other effects of noise on their intrinsic health (such as ischemic heart diseases) and that these effects are therefore not included in the WTP values found from HP

studies. These external health costs may then be disregarded in the study, or some generic estimation is assumed (e.g. health costs are 50% of the WTP for annoyance).
An alternative is to use stated preferences methods, but original contingent valuation studies for traffic noise are less common. The generic WG HSAE value of 25€/dB/household/year is often referred to. This value was obtained for road noise, however, and evidence shows that values for rail noise are generally lower, while values for aircraft noise are generally higher. It should also be noted that the accuracy of these values is limited and may not be applicable to any location. New and country-specific values found from the HEATCO project are therefore a better alternative. Nevertheless, care should be taken in the interpretation of the exact results, since the margins around the monetary values are likely to exceed ± 50%.

We have seen several examples of decision methods being applied in national legislation or in specific studies and projects. We know from the survey results that there are also many cases and countries where decisions on noise abatement measures are taken using more rudimentary methods, or by relying on the common sense and intuition of acoustic engineers and local policy makers. Common sense is definitely important for these decisions, as no method exists that automatically provides the best answer for all situations. But the use of a common decision making method will help in making the best decisions that will help to gain the largest improvement on public health as a whole. Especially in a situation with limited budgets, it is important to spend it such that most people benefit from it. Using a fair and transparent method also helps to increase public acceptance.

8.2 Recommendations

For policy makers looking to introduce or to improve their decision making methods for noise abatement measures, we recommend the following:

- A well-defined and described decision making method, including prescribed cost/benefit calculations, is recommended to enable a fair comparison of the noise problem in one location to the problem another. Transparent methods increase fairness and acceptance and may prevent legal issues with noise in projects.
- Good examples of methods that have been successfully implemented in national legislation already exist. We recommend that policy makers do not invent their own, new methods, but look to other European countries for best practice. Best practice guidelines may also be provided on a European level, perhaps by the EPA Network.
- A good method should include:
  - a clear and complete definition of costs, including investment as well as maintenance costs. If passive noise measurements, such as façade insulation and property value compensation, are considered as an alternative, costs should also be calculated for these;
  - a well-defined quantity for the benefits, that includes annoyance, sleep disturbance and other relevant health effects. Monetary values are an option, but the WTP values should be carefully chosen and documented, so as to make decisions comparable. Uncertainties in these values should be clearly reported;
  - considerations for other criteria (see Chapter 7) should be included in the decision making. These criteria could be made part of the cost/benefit analysis, using MCDA or CBA, but at least they should be a clear part of the process; see for instance the German example in 6.3.4.
- Noise limit values are not a prerequisite for a cost/benefit method, but the opposite does seem to be true:
  - For the evaluation of cost effectiveness, noise limits are not required. Noise limits may help, however, to limit the workload, for instance: above a certain maximum level, noise measures must be taken at any cost; below a certain minimum level, noise measures are not considered. Cost effectiveness calculations are only needed for the in-between cases.
  - In a system with noise limits, there is a need for cost-benefit evaluation to avoid very high costs for limited extra benefits. The money needed for a very high noise barrier near a single high apartment building may help more people if spent elsewhere.

Based on the conclusions in paragraph 8.1, we give the following recommendations for choosing a decision method with regard to traffic noise abatement measures:

- For specific projects, where the noise limits are clearly set from legislation, a balance is needed between costs and noise reduction. We recommend to look not only at cost minimisation, but also at cost effectiveness by regarding the extra noise reduction vs. the extra costs of various abatement measures.
- For these specific projects, we recommend to consider MCDA as an alternative tool to include other aspects, such as aesthetics, socio-cultural and social security aspects. MCDA takes more time and effort, compared to a cost effectiveness study, but it is relatively easy to implement for local projects, it enables emphasizing policy aspects and it stimulates public involvement. We find that the objectiveness and straightforwardness associated with CBA are limited, since the outcome relies on the accuracy of the monetarisation values obtained or chosen and since some criteria may be disregarded because they cannot be monetarised.
- For national policy development, we recommend CBA, since this is the only method that enables the establishment of an absolute level for the budget that is available for noise abatement measures.

In the case of CBA, we give the following recommendations for monetarisation of external health and annoyance costs:

- We have not found a clear preference for hedonic pricing vs. stated preferences methods with respect to the results for traffic noise annoyance; both methods have pros and cons. HP may be easier and less expensive to conduct, depending on the data available from both the real estate market and the noise exposure.
- With regards to CV studies, questions should be appropriate and understandable. The stated preferences surveys from HEATCO [27] are a good starting point.
- We recommend to provide each CBA outcome with realistic information on the criteria that have been incorporated and the monetarisation values that have been used. Expectations on the accuracy of the results should be carefully managed.

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Appendix A – Eionet survey

EIONET questionnaire: decision methods and cost/benefit for noise abatement measures

The interest group on traffic noise abatement (IGNA) is presently preparing its final reporting to the EPA-network for the end of 2016. The reporting contains an overview of cost-benefit methods that are crucial for making decisions to enforce noise abatement measures.
For this purpose IGNA has developed a questionnaire to obtain information about methods used for making decision on traffic noise abatement measures in the EU-countries. We want to have an overview and comparison of national legislation in European countries with respect to balancing costs versus public benefits. We are also looking for examples of road, rail and aircraft projects where methods have been applied.
Therefore, we would be very grateful if you could spend a few minutes to fill in the questionnaire.
Thank you very much for your time and cooperation.

<u>Contact information</u>

Name	
Country	
Organisation	
Department	
E-mail address	

<u>Survey scope</u>
For all questions, we would like to distinguish between road, rail and aircraft noise. If the decision making methods and/or legislation are quite different for these three types of transportation, we would prefer if you fill in the survey separately for road, rail or aircraft noise; please indicate for which category or categories your answers apply. If you can only answer these questions for one or two categories, that would still be very helpful.

1. My answers apply to (*multiple answers allowed*):
   - ☐ road traffic noise
   - ☐ rail traffic noise
   - ☐ aircraft noise

<u>Survey questions</u>

2. Legislation or common practice for noise measure cost considerations:
   A. Does traffic noise legislation in your country contain any formalized cost considerations, e.g. does legislation prescribe how to determine the budget available for noise abatement measures (e.g. source measures, noise barriers, facade insulation)?
      - ○ yes (*go to question 3*)
      - ○ no

   B. If cost considerations are *not* part of the legislation, are there any methods that are used as 'common practice' to determine whether or not a noise abatement measure is financially justified? Any details or comments may be provided below
      - ○ yes
      - ○ no

3. Relevant traffic noise situations:
   A. To what situations do these cost considerations apply? (*multiple answers allowed*)
      ☐ improvement of existing high noise levels (e.g. noise sanitation)
      ☐ reconstruction of or adaptations to existing infrastructure
      ☐ new infrastructure
      ☐ other situations (*please explain below*)

   B. If you have selected multiple answers, there may be differences in the application of cost considerations between the various traffic noise situations. If so, please explain the differences below:

NOTE: *All further questions apply to both legislation, if existing, or any common or best practice methods that are applied in your country.*

4. Total budget for noise abatement measures:
   A. In your country, is there a total budget available for noise abatement (per year, or for a certain period of years)?
      ○ yes
      ○ no (*go to question 5*)

   B. If so, could you explain how the height of this budget has been determined?

5. Please summarize how to determine if the noise reduction of a noise abatement measure is sufficient to justify its costs, for a particular traffic noise situation or infrastructure project. *Feel free to refer to or send any public reports or documents instead of describing details here.*

6. To what extent is the cost effectiveness of a noise abatement measure accepted as a reason not to meet the legally required or desired noise limits?

7. In your decision making method, which costs of noise abatement measures are included ? (*multiple answers allowed)*
   ☐ direct costs of noise abatement measures, e.g. construction of noise barriers, low-noise pavements, traffic signs for speed limits, etc.)
   ☐ maintenance costs for abatement measures, e.g. cleaning and repair, repavement, etc.
   ☐ ‘passive’ noise abatement measures, e.g. façade insulation
   ☐ compensation for value loss of real property (in case of expropriation)
   ☐ time loss of enforced speed limits with regard to former speed
   ☐ administrative costs of authorities
   ☐ legal disputes
   ☐ other costs (*please explain below*)

8. In your decision making method, how are the benefits of noise abatement measures to be quantified?
   - ○ quantify the noise reduction, e.g. in dB, or dB * (number of persons/households affected)
   - ○ quantify the effect on health and annoyance, e.g. using DALY, QALY or a different health indicator
   - ○ quantify the effect in monetary units
   - ○ quantify on a different scale (*please explain below*)
   - ○ other method (*please explain below*)

9. Monetarisation of benefits:
   A. Do you quantify benefits (e.g. decreased annoyance and/or health impacts) in monetary units?
      - ○ yes
      - ○ no (*go to question 10*)

   B. What methods are used for monetarisation?
      - ○ by relating the effect of noise levels to real estate and/or land pricing or house/apartment rents (hedonic pricing)
      - ○ by using values for willingness to pay/accept from direct questionnaires (stated preferences, contingent valuation)
      - ○ by using prescribed values, from other reference studies, or from a source unknown to you
      - ○ other method (*please explain below*)

   C. What values do you use for monetarisation? Please also specify the unit, e.g. €/dB/household/year, % decrease of property prices, or any other unit.

10. Other decision criteria:
    A. What other criteria are included in the decision making process for noise abatement measures in your country?
    Multiple answers are allowed. Any details may be provided in the text box below.
       - ☐ technical limitations, e.g. bridge carrying capacity, space limitations for barriers, etc.
       - ☐ safety considerations, including social security
       - ☐ maintenance requirements and limitations, not already covered in the costs
       - ☐ aesthetic considerations, e.g. impact on the visual landscape, either for the traffic user or for the people living or working nearby
       - ☐ social and cultural considerations, e.g. impact on the city character, cultural inheritance
       - ☐ added secondary benefits: benefits from the noise abatement measure besides the noise reduction
       - ☐ preferences towards innovative noise measures, or research benefits
       - ☐ other criteria (*please explain below*)

B. How are these additional criteria combined with the cost effectiveness considerations described earlier? Are these separate considerations, described in separate documents, or are they integrated somehow in the decision making process?

11. Can you describe one or more good examples where the decision methods and criteria described above have been applied for noise abatement measures?
These examples may include specific road, rail or aircraft infrastructure projects on any scale, and may also include examples of policy development on national or local level. Feel free to refer to or send public reports or documents, instead of describing details here.

12. Can you describe any bad examples of decision making for noise abatement measures?
Examples may refer to wrong methods being applied (overkill or oversimplification), missing criteria, low acceptance of results by the public, legal issues, or any examples actually leading to a 'wrong' decision.

13. Your opinion on current practice:
    A. What is your opinion on the current practice of decision making on noise abatement measures in your country?

    B. To your opinion, how could the current practice in your country be improved?

14. Any links to documents or reports describing your national legislation or current practice may be provided below, or you may send these separately through e-mail: bertpeeters@mp.nl

Thank you very much for your time and cooperation!