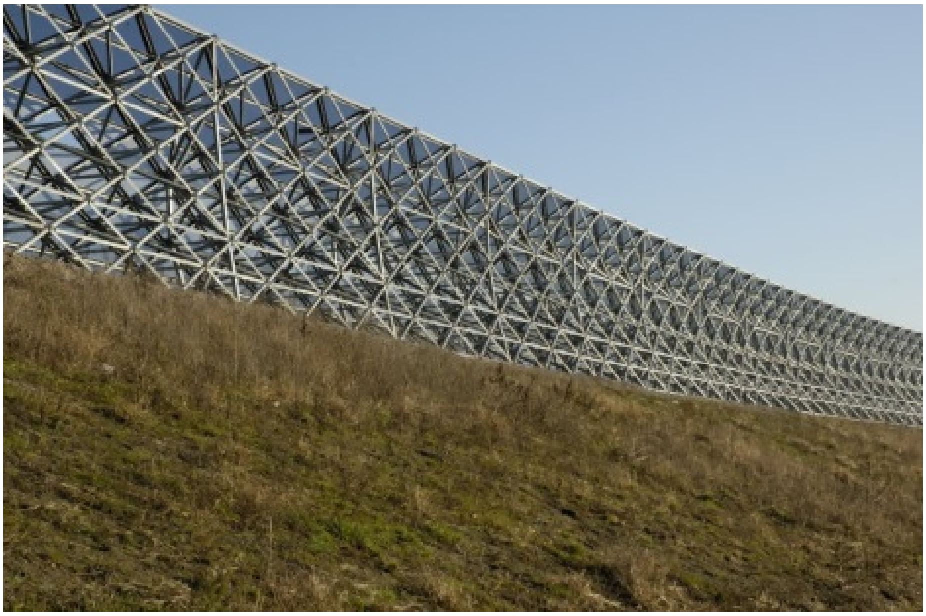
Health Impact Assessment

for

Noise in Europe

Expected consequences of the limitations

of the available noise exposure data



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European Topic Centre
on Air Pollution and
Climate Change Mitigation

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Front page picture:
Sound barrier along highway A2 at Leidsche Rijn, Utrecht, The Netherlands

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Synopsis

Health Impact Assessment for Noise in Europe

This report describes the impact on health and well-being of road traffic, railway and aircraft noise in Europe based on the second round of noise mapping in the framework of the European Noise Directive.

Exposure to noise from road traffic, railways or aircrafts leads to annoyance among 53 million adults; 21 million of them are highly annoyed. 34 Million adults are expect to experience noise related sleep disturbance; 14 million of them are severely sleep disturbed. Almost 1.7 million additional prevalent cases of hypertension in 2012 can be contributed to environmental noise. This is expected to result in 80 thousand additional cases each year of hospital admissions and to 18 thousand cases of premature mortality each year due to coronary heart disease and stroke.

In addition we estimated that for 270 million residents in Europe the night-time noise guideline of the WHO (40 dB L_{night}) is exceeded.

The reported impact is still an underestimation. Areas outside major agglomerations or not influenced by noise from major roads, major railways and major airports are not included in this study.

An important source of uncertainty in the health impact assessment could have been avoided if more reporting states had met the date of December 30, 2012 for the reporting of second round of noise mapping.

We imputed the missing data in the latest available database of the second round of noise mapping. Since the database only includes levels above 55 dB L_{den} and 50 dB L_{night}, we extrapolated the noise exposure distribution downwards to levels as low as 40 dB L_{den}. The results of the study stress the importance of lower noise levels for the size of the health impact of community noise.

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

Contents

Summary

The objective of the current study is to update the results of the health impact assessment as reported in 'Noise in Europe 2014' and to quantify the uncertainties related to the incompleteness of the reported data in June 2014 and by the limitation of the exposure data by the requirements of European Noise Directive (END).

The following limitations are present in the data collected in the framework of the END:

1. The data delivery is not completed yet for the reporting of the second round of noise mapping.
2. The END assessment is limited to the population living above the mandatory values for noise mapping of ≥55 L_{den} or ≥50 L_{night}. Also below these levels, there is a risk for health and well-being effects due to noise exposure.
3. The END assessment is limited to major agglomerations, major roads, major railways and major airports.

Due to these three limitations, data collected in the framework of the END cannot be used directly for a health impact assessment but should be completed first. Completion in this sense means to impute (missing) data for those situations where data should have been delivered but was not, to extrapolate END data to lower exposure levels and to predict the noise exposure for areas not covered by the END.

The completeness for road traffic and railway noise is in total 57%. In total, the L_{den} level was reported for 69 million residents. The noise level was imputed for an additional 52 million residents leading to total of 121 million residents. The completeness varied between 43 (railways noise inside major agglomerations) and 87% (major roads).

In the second step, we extrapolated the noise exposure distributions for noise from roads and from railways in large agglomeration and from major roads and major railways to lower levels using information from the distributions above 55 dB L_{den}. This led to a total population of 408 million residents in the four assessments. This population is about six larger than original reported (69 million).

After imputation of the missing data and extrapolating of the noise exposure distribution to lower levels, it is estimated that for 270 million residents in Europe the night-time noise guideline of the WHO (40 dB L_{night}) is exceeded. For 47 million of them, the night-time exposure does not comply with the interim WHO guideline of 55 dB L_{night}.

It is estimated that at least 53 million adults are annoyed due to noise from road traffic, railways or aircrafts; 21 million of them are highly annoyed. 34 Million adults are expect to experience noise related sleep disturbance; 14 million of them are severely sleep disturbed. Environmental noise exposure contributed to almost 1.7 million additional prevalent cases of hypertension in 2012, to 80 thousand additional cases each year of hospital admissions and to 18 thousand

cases of premature mortality each year due to coronary heart disease and stroke. 75 to 85% Of the health impact is related to road traffic noise exposure.

The reported impact is an underestimation since the health impact in areas no covered by the END is not included in the estimations.

The increase in the number of (severe) annoyed residents compared with the results in 'Noise in Europe 2014' relates for about 58% to the incompleteness of the END database 2012. It is expected that extrapolating noise levels from a complete database to lower levels will increase the size of annoyance with another 71% and of severe annoyance with another 50%.

The size of (severe) sleep disturbance was underestimated by 63% due to the incompleteness of the database. It is estimated that extrapolating night-time noise levels of a complete database to lower levels will lead to 158% more cases of sleep disturbance and 135% more cases of severe sleep disturbance. This relative high contribution of sleep disturbance at low exposure levels is a result of the relative high level of that was selected as lower limit of the noise assessment in the END (50 dB L_{night}).

For the cardiovascular endpoints (hypertension, hospital admissions and premature mortality) imputation of the missing data in the END database leads to a similar increase as for annoyance (59%). Extrapolating noise levels to lower levels has a smaller impact: the burden of disease increases with 14%.

The results differ per source. The changes in the exposure distribution for road traffic noise in large agglomerations due to imputation or due to extrapolation contribute, in absolute numbers, the most to the increase in the size of the health impact.

The results of the study stress the importance of lower noise levels for the size of the health impact of community noise. The population at risk for night-time noise is underestimated by a factor 3 when the mandatory level in the END L_{night} assessment (50 dB) is used for risk assessment. It is recommended to use at least the night-time noise guideline of the WHO as lower level of a noise assessment in studies aimed on risk evaluation or on health impact assessment.

Introduction

In December 2014, the European Environmental Agency (EEA) published 'Noise in Europe 2014' (EEA, 2014) in which, among other, the provisional results of a health impact assessment for exposure to community noise were presented.

The reported results in 'Noise in Europe 2014' are the spin-off of a study that had been carried out in 2014 by order of the European Commission, DG Environment. This study was a quantitative description of the health and well-being implications of road, railway and aircraft noise in the European Union, with the focus on an update of the methodology based on the latest available knowledge (Houthuijs et al., 2014). The methodology was at that time applied on the latest available database (August 2013) with exposure data that resulted from the second round of noise mapping in the framework of the European Noise Directive (END).

The objective of the current study is to update the results of the health impact assessment as reported in 'Noise in Europe 2014' and to quantify the uncertainties related to the incompleteness of the reported data in June 2014 and by the limitation of the exposure data by the requirements of END.

The main objective of the data that results from the END is to provide information on noise exposure in the reporting countries, which forms a basis for further noise policy development. The reporting countries describe their developed policy in their action plans. Using the exposure data for a health impact assessment is not an objective of the END and therefore a different application for the collected noise data. This report addresses how the collected data can be used for health impact assessment and how uncertainties and limitations influence the results of the health impact assessment.

In this report we quantify the size of the health and well-being effects of noise. The results offer the opportunity to evaluate the impact of community noise and to compare and prioritise this impact with the impact of other (environmental) agents.

In Chapter 2 the exposure assessment and its uncertainties are discussed, and our general approach to overcome the limitations is described. In Chapter 3 the noise exposure distributions are presented after imputation of missing data and extrapolating to lower noise levels. The results of the health impact assessment are given in Chapter 4. The report ends with a discussion (Chapter 5) and conclusions (Chapter 6).

1 Methods to estimate the noise exposure distributions

1.1 Introduction

In this chapter we describe the methods that we applied to estimate the number of people exposed to community noise in Europe.

The data prepared by the reporting countries in the context of the END are the starting point for our exposure assessment. In the framework of the second round of noise mapping of the END, an assessment for the following areas and/or sources was required:

- Noise from road traffic, railway and industrial sources in major agglomerations (more than 100.000 inhabitants)
- Noise from majors roads (more than 3 million vehicles per year)
- Noise from major railways (more than 3 million trains per year)
- Noise from major civil airports (more than 50.000 movements per year)

The reporting countries are not required to make noise maps for their whole territory.

1.2 Uncertainties and limitations of the exposure data

The reported END data provides in structured way information about the population exposure. The data results from modelling that is carried out by the reporting countries themselves. The data contains typical uncertainties caused by the model structure(s), model parameters, software implementation and input data.

The results for agglomerations show a wide range in the percentage of population exposed to 55 dB L_{den} or more. The variation might be caused by actual distinctive features of the agglomerations (e.g. delineation, area, population density, etc.) but may be well caused by difference in input data, software implementation, structure of models themselves and assumptions how residents are distributed in buildings when the exposure is attributed to the population. These factors are recognised to be of crucial importance in the process of developing a harmonised calculation method (Kephalopoulos, Paviotti and Anfosso-Lédée, 2012).

Up until now, the influence from the variation in models, from differences in software implementation and from data providers who supply input data with differences in quality are ignored. This is so-called recognised ignorance. Unfortunately, the influence on the results of this ignorance is hard to quantify. Only information about the applied calculation method is requested to be provided.

In addition to the recognised ignorance, the following limitations are present in the data collected in the framework of the END.

4. The data delivery is not completed yet for the reporting of the second round of noise mapping.
5. The END assessment is limited to the population living above the mandatory values for noise mapping of ≥55 L_{den} or ≥50 L_{night}. Also below these levels, there is a risk for health and well-being effects due to noise exposure. Reporting countries have been asked to

provide information about the size of the population in lower noise bands on voluntary basis. So far, the provided information is very limited.

6. The END assessment is limited to major agglomerations, major roads, major railways and major airports.

These three limitations are easy to recognize and can therefore be seen as a major deficiencies because, ignoring other uncertainties, they lead to a structural underestimation of the health impact of community noise.

Due to these three limitations, data collected in the framework of the END cannot be used directly for a health impact assessment but should be completed first. Completion in this sense means to impute (missing) data for those situations where data should be delivered but was not, to extrapolate END data to lower exposure levels and to predict the noise exposure for those situations not covered by the END and therefore not available on a European level.

1.3 General approach to estimate the noise exposure distributions

The general approach for completing the exposure data was three folded. The first two approaches make use of the data collected in the framework of the END. In addition, we explored the possibility to estimate the noise exposure in locations not included in the END.

1. Imputation of missing data from the END database
The first approach is to impute data in the situation where reporting countries should have provided END data, but have not done so. The missing data will be imputed applying methodologies described by Burdett and Williams (2012). We mainly applied: 1) using available data for 2007 as a proxy for the 2012 situation, or 2) substitute missing data with similar 2012 data from the same or other countries.

2. Extrapolation of END data to lower exposure levels
The second approach is enriching the data from the END. Enrichment in this context means extrapolating the END data to populations for which there is no obligation to report the noise exposure since this is below the mandatory level of 55 dB L_{den} or 50 dB L_{night}. A simple but effective method to estimate the noise distribution in these populations is the application of a statistical model partly based on information about noise levels above the 55 dB L_{den} or 50 dB L_{night}.

3. Prediction of noise exposure in locations not covered by the END
The third approach was to explore the possibility to predict the noise exposure in locations not included in the END. From a practical viewpoint, we limited this approach to road traffic noise, so to exposure from roads with less than 3 million vehicles per year and from roads in smaller agglomerations. De Vos and Van Beek (2011) described a methodology to estimate the noise distribution in (urban) study areas making use of data on population density.

In Chapter 3 we describe in more detail how we applied this general approach for the various combinations of noise source and location.

2 Estimated noise exposure distributions

2.1 Introduction

In the paragraphs 3.2 to 3.7 we describe per source and per location how we imputed missing data for the second round of noise mapping, how we extrapolated the noise data to lower levels and how we predicted noise exposure levels in locations not covered by the END. The resulting estimated noise exposure distributions are described. These distributions are used for health impact assessment (see Chapter 4). In paragraph 3.8 we give an overview of the consequences of the imputation and the extrapolation for the number of residents in the various assessments. In paragraph 3.9, we compare the estimated noise exposure distributions with health based guideline levels.

The report addresses noise exposure from roads, railways and airports in the EEA33 (EU28 plus Island, Liechtenstein, Norway, Switzerland, Turkey). We used the latest available database[1] (10 June 2014). We did not include industrial noise in our assessment since we expected a very limited contribution from this source to the total size of the health impact assessment.

2.2 Road traffic noise within major agglomerations

2.2.1 Applied methods to estimate the noise exposure distribution

The reported data in the 2012 END database are the starting point. For those agglomerations for which the data was not yet reported, we imputed the missing data for 2012 in 4 steps following the methodologies described by Burdett and Williams (2012). First, missing data was replaced by results obtained in the first round of noise mapping (2007) for the same agglomeration. If these results were not present, we scaled country-specific information about the noise exposure distribution in 2012 according to the population size of the agglomeration. In the case that no information was available for 2012, we used country-specific information about 2007. Lastly, if country-specific information was unavailable for 2012 and 2007, we scaled European-wide information about the noise distribution in 2012 according to the population size of the agglomeration. For some of the agglomerations there was no information about the population size available; these agglomerations were excluded from the dataset. The results of the imputation process are given for the L_{den} exposure distribution in Table 3.1.

Liechtenstein, Freistaat Thüringen and Malta were excluded from the dataset (not relevant since no agglomerations present or no obligation to report). For Turkey no estimation was made since there was no information on the population within the agglomerations reported.

[1] END_DF4_DF8_Results_2012_140610: http://forum.eionet.europa.eu/etc-sia-consortium/library/noise_database/end_df4_8_results_2012.xl

Table 3.1: Data source for road traffic noise exposure (L_{den}) within major agglomerations for 473 agglomerations

Data-source	# Of agglomerations	Population (* million) ≥55 dB L_{den}
Noise database 2012	318 (67%)	40.8 (50%)
Noise database 2007	67 (14%)	32.8 (40%)
Country specific results of 2012 used	54 (11%)	4.6 (6%)
Country specific results of 2007 used	19 (4%)	2.8 (3%)
European-wide results of 2012 used	14 (3%)	1.2 (1%)
No estimation for 2012	1 (0.2%)	-

For two third of the agglomerations data from 2012 was used. We imputed the noise exposure for 41.5 million residents leading to a total population of 82 million residents in major agglomerations for which the road traffic noise exposure equal to or above 55 dB L_{den} is 'available'.

To extrapolate the noise exposure distribution of these 82 million residents to lower levels, we used a statistical model based on the available data for noise levels above 55 dB L_{den} (and 50 dB L_{night}). Instead of using a deterministic statistical model, we decided to let the available data speak for itself. We estimated with a statistical model the full exposure distribution per decibel within an agglomeration based on the number of exposed residents in the 5 dB L_{den} categories above 55 dB, and the remaining number of inhabitants within the agglomeration in the category below 55 dB. For details, we refer to Annex 1.

2.2.2 *Estimated noise exposure distribution*

In Figure 3.1 the estimated distributions for L_{den} and for L_{night} are shown as fraction of the total population in the 472 agglomerations (176 million inhabitants).

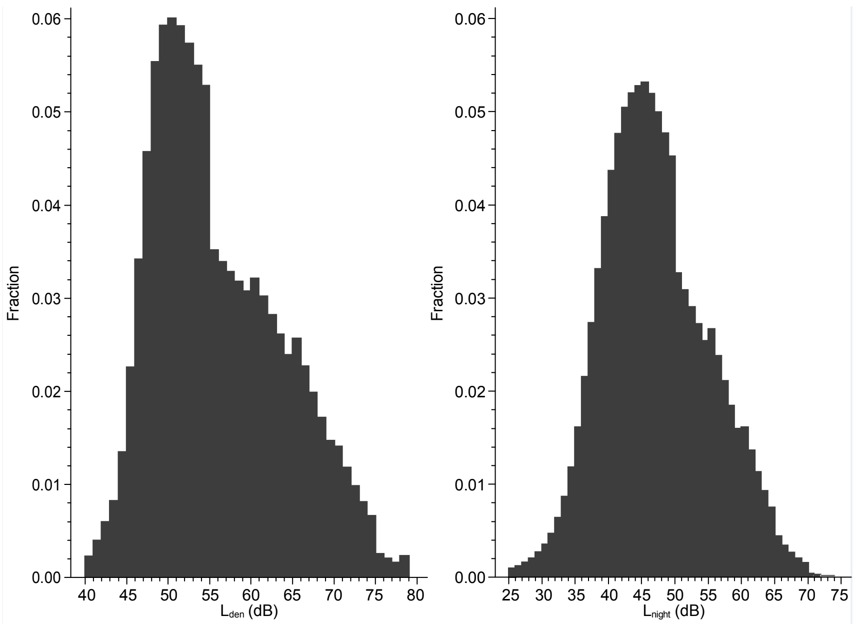

Figure 3.1: Estimated exposure distributions for L_{den} and L_{night} for residents inside agglomerations in 472 agglomerations

The mean (median) L_{den} of the estimated distribution is 56.1 (54.5) dB; the mean (median) L_{night} 47.2 (46.5) dB. The estimated mean difference between L_{den} and L_{night} in the 472 agglomerations is 9 dB. Other statistical characteristics of the distributions are given in Annex 2.

2.3 Noise from major roads outside agglomerations

2.3.1 Applied methods to estimate the noise exposure distribution

A database for road traffic noise from major roads was compiled by combining the results from 2012 with data for 2007 for those countries (or regions within countries) where the data was not available yet. In the latter situation, the size of the population was increased by 5.3% to obtain estimated results for 2012, as was described by Burdett and Williams (2012). If there was no information available for both years (2007 or 2012), the country was excluded from the dataset.

The results for 55 regions or countries in the EEA33 are given for the L_{den} exposure distribution in Table 3.2. We choose to report the region results in Table 3.2 as well, since some countries report per region and the completeness can differ between regions.

Table 3.2: Data source for road traffic noise exposure (L_{den}) from major roads for 55 regions in the EEA33

Data-source	# Of regions/countries	Population (* million) ≥55 dB L_{den}
Noise database 2012	39 (71%)	20.3 (89%)
Noise database 2007	10 (18%)	2.6 (11%)
No estimation for 2012	6 (11%)	

For 2.6 million residents, the L_{den} exposure distribution was imputed leading to a population of 22.9 million residents.

For Greece, Macedonia and Turkey and three regions (Berlin, Brussels and Hamburg) there was no data available for both 2012 and 2007.

We estimated the noise levels below 55 dB L_{den} (and 50 dB L_{night}) with a statistical model based on the available data for noise levels between 55 and 60 dB L_{den}. We used this specific exposure category, since it is unlikely that the size of the population living in this category is affected by mitigation measures. We therefore expect that the population size of this category correlates better with the population size of lower exposure bands than the population size of exposure categories ≥60 dB. We used noise exposure data from all motorways in the Netherlands (source Netherlands Environmental Assessment Agency, 2008) to derive the population living at noise levels between 40 and 55 dB L_{den} (resolution 1 dB) as fraction of the population living between 55 and 60 dB L_{den}. The assumption is that this fraction is transferable between countries. The same exposure distribution from the Netherlands was used the refine the exposure from 5 to 1 dB categories for the exposure categories above 55 dB L_{den}. The total number of residents within a 5 dB category was not allowed to change, so the data from the Netherlands

was only used to redistribute residents within the 5 dB categories above 55 dB L_{den}.
Based on the estimated exposure distribution for L_{den} per country with a 1 dB resolution, the L_{den} level was assessed for which the cumulative number of residents equal or above this level corresponded with the cumulative number of residents living equal or above a noise level of 50 dB L_{night}. The estimated (mean) difference between L_{den} and L_{night} in combination with the population distribution for L_{den} was used to project the night-time noise exposure under 50 dB L_{night}. Again, above 50 dB L_{night} the shifted L_{den} distribution (based on the estimated difference) was only used to refine the L_{night} distribution within its 5 dB categories.
We limited the assessment area for road traffic noise from major roads to the estimated 40 dB L_{den} contour. Within this assessment area the full L_{night} distribution was estimated as described above to ensure that the number of residents in both assessments were equal.

2.3.2 *Estimated noise exposure distribution*

In Figure 3.2 the estimated distributions for L_{den} and for L_{night} for major roads are shown as fraction of the total population within the 40 dB L_{den} contour (125 million residents).

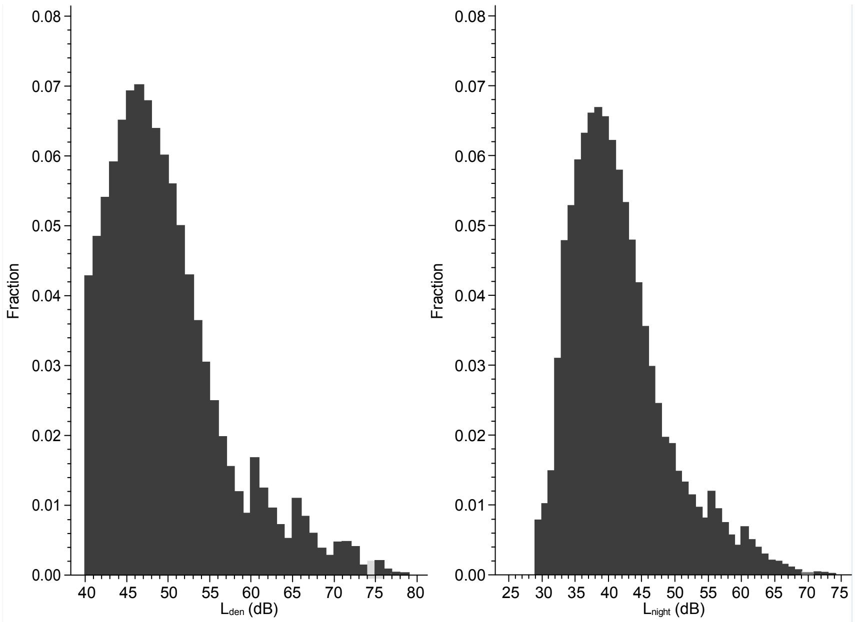

Figure 3.2: Estimated distribution for L_{den} and L_{night} within 40 dB L_{den} contour for major roads outside agglomerations

The mean L_{den} of the estimated distribution within the 40 dB L_{den} contour is 49.8 dB; the mean L_{night} 41.6 dB. The estimated mean difference between L_{den} and L_{night} is for noise from major roads 8 dB. Other statistical characteristics of the distributions are given in Annex 2.

2.4 Road traffic noise outside agglomerations and not from major roads

Apart from the assessment areas for major roads, major railways and major airports and major agglomerations there is also exposure to noise from roads, railways and aircrafts in other areas in Europe. These areas are not covered by the END, but could be included in a health impact assessment if the distributions of the noise exposures were known.

We explored the applicability of the methodology described by De Vos and Van Beek (2011). They concluded that the correlation between population density and road traffic noise exposure is strong enough to use it for the prediction of the population exposure distribution in smaller agglomerations not covered by the END. A similar association had been found earlier (Galloway et al., 1974).

We could not assess any relation between the population density of the major agglomerations and their exposure distribution for road traffic noise in the current END database. For this reason, it was not possible to apply the methodology described by De Vos and Van Beek (2011).

Since the END consists of agglomerations with different sizes, we explored the role of the size of aggregation with data on road traffic noise in The Netherlands (source Netherlands Environmental Assessment Agency, 2008)

We defined grids of 200 by 200 and 500 by 500 meters and 1 by 1, 2 by 2, 3 by 3, 4 by 4 and 5 by 5 kilometres and subsequently calculated for each grid the population density as well as the noise exposure distribution as fractions of 5 dB L_{den} exposure categories (<40 to ≥70 dB). The noise exposure distribution was assessed twice: including and excluding noise from motorways. As next step we carried out a so-called stereotype logistic (SL) regression. SL models are used for categorical dependent variables (the exposure categories). With this regression model, the whole exposure distribution can be fitted in one statistical analysis in relation to the population density.

The results of the statistical analyses indicated that the best fit was obtained for a grid size of 3 by 3 km when noise from motorways was excluded and for a grid size of 5 by 5 km if this source was included. In Figure 4.3 we plotted as example the predicted population fraction per 5 dB L_{den} exposure category as function of the population density for the grid size of 3 by 3 km excluding noise from motorways.

Since the statistical analysis was explorative, we did not use the outcome of the model yet to estimate the exposure distribution for road traffic noise outside agglomerations in the EEA33. The next step would be to search for additional data that may improve the prediction of the model and that is European wide available. From the results of the explorative analyses we learn that this data should be available at a detailed level, starting at a grid size of 1 by 1 km.

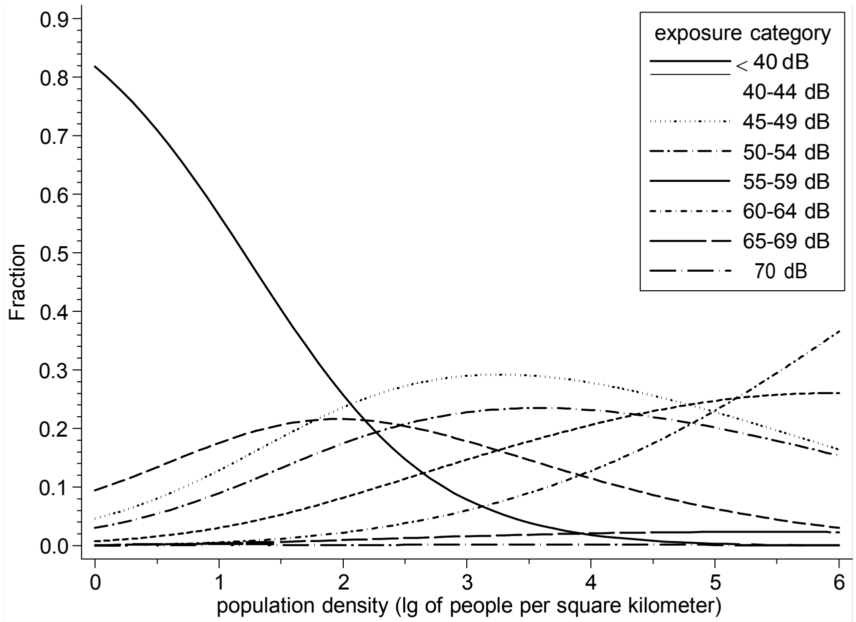

Figure 3.3: Predicted population fraction per 5 dB L_{den} road traffic noise exposure category as function of the population density (people per square km), based on a grid of 3 by 3 km and excluding noise from motorways

2.5 Railway noise within major agglomerations

2.5.1 Applied methods to estimate the noise exposure distribution

For those agglomerations where the data on railway noise was not yet reported, we imputed the missing data for 2012 in 2 stages following the methods described by Burdett and Williams (2012). First, missing data was replaced by results obtained in the first round of noise mapping (2007) for the same agglomeration. For the remaining agglomerations country-specific information was unavailable for 2012 and 2007. We scaled European-wide information about the noise distribution in 2012 according to the population size of these agglomerations.

The dataset contained three agglomerations that were not under the obligation to report; these agglomerations were excluded from the database. For 12 agglomerations it was not possible to make any estimation because there was no information about the population size available. The results of the imputation process are given for the L_{den} exposure distribution in Table 3.3.

For 60% of the agglomerations and 43% of the population data from 2012 was used. We imputed the L_{den} noise exposure above 55 dB for 5.4 million residents leading to a total population of 9.4 million residents in major agglomerations for which (estimated) information about higher exposure levels is available.

Table 3.3: Data source for railway traffic noise exposure (L_{den}) within 473 major agglomerations

Data-source	# Of agglomerations	Population (* million) ≥55 dB L_{den}
Noise database 2012	285 (60%)	4.0 (43%)
Noise database 2007	62 (13%)	4.4 (47%)
Country specific results of 2012 used	-	-
Country specific results of 2007 used	-	-
European-wide results of 2012 used	114 (24%)	1.0 (11%)
No estimation for 2012	12 (3%)	

Since the exposure the noise from railways is limited to a certain area of the agglomeration, we applied a similar methodology as was carried out for road traffic noise from major roads to estimate the exposure to lower levels (see paragraph 3.3.1). We used noise exposure data from all railways in the Netherlands (source Netherlands Environmental Assessment Agency, 2008) to derive the population living at noise levels between 40 and 55 dB L_{den} (resolution 1 dB) as fraction of the population living between 55 and 60 dB L_{den}. Subsequently, we estimated a noise exposure distribution for L_{den} and for L_{night} with a 1 dB resolution for an assessment area restricted by the estimated 40 dB L_{den} contour.

2.5.2 *Estimated noise exposure distribution*

In Figure 3.4 the estimated distributions for L_{den} and for L_{night} for railway noise are plotted as fraction of the total population within the estimated 40 dB L_{den} contour (58 million residents).

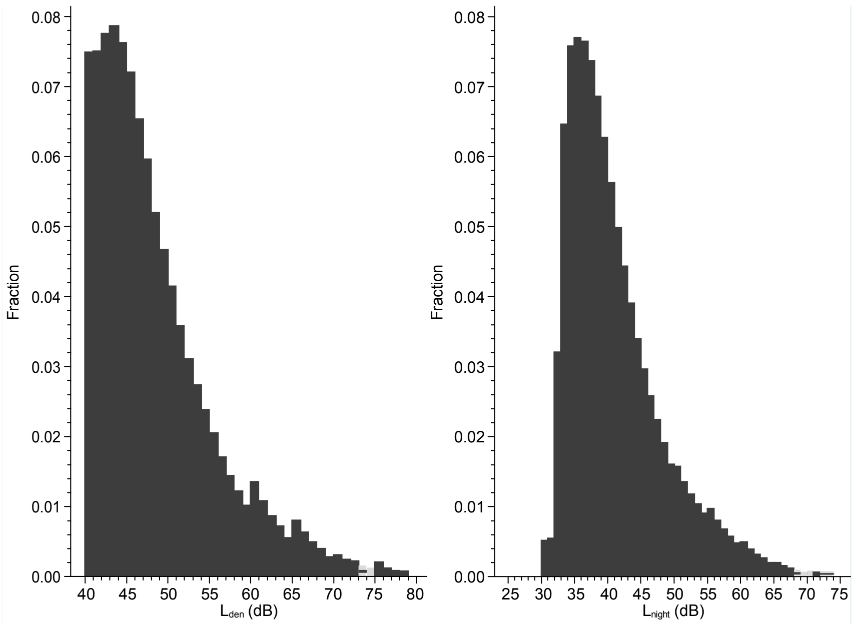

Figure 3.4: Estimated distribution for L_{den} and L_{night} within 40 dB L_{den} contour for railway noise within major agglomerations

The mean L_{den} of the estimated distribution for railway noise within the 40 dB L_{den} contour in major agglomerations is 48.6 dB; the mean L_{night}

41.2 dB. The estimated mean difference between L_{den} and L_{night} in the agglomerations is 7 dB. Other statistical characteristics of the distributions are given in Annex 2.

2.6 Noise from major railways outside agglomerations

2.6.1 Applied methods to estimate the noise exposure distribution

A database was compiled following the methodology described by Burdett and Williams (2012). For regions where the data was not yet available, data for 2007 was used. The population in the exposure categories of 2007 was increased with 15.5% to estimate the results for 2012.

The results for 39 regions/countries in the EEA33 are given in Table 3.4.

Table 3.4: Data source for railway noise exposure (L_{den}) from major railways for 39 regions in the EEA33

Data-source	# Of regions/countries	Population (* million) ≥55 dB L_{den}
Noise database 2012	23 (59 %)	3.8 (54%)
Noise database 2007	5 (13 %)	3.2 (46%)
No estimation for 2012	11 (28%)	-

17 regions were excluded from the dataset because these regions did not have an obligation to report since major railways lines were not present. For 11 regions, no estimation could be made due to absence of information on the length of the major railway tracks.

For 3.2 million residents, the L_{den} exposure distribution above 55 dB was imputed leading to a population of 7 million residents.

Since the exposure the noise from railways is limited to a certain area of the country, we applied a similar methodology as was carried out road traffic noise from major roads (paragraph 3.3.1). We used noise exposure data from all railways in the Netherlands (source Netherlands Environmental Assessment Agency, 2008) to estimate a noise exposure distribution for L_{den} and for L_{night} with a 1 dB resolution for an assessment area restricted by the estimated 40 dB L_{den} contour.

2.6.2 Estimated noise exposure distribution

In Figure 3.5 the estimated distributions for L_{den} and for L_{night} for noise from major railways outside agglomerations are shown as fraction of the total population within the estimated 40 dB L_{den} contour (48 million residents).

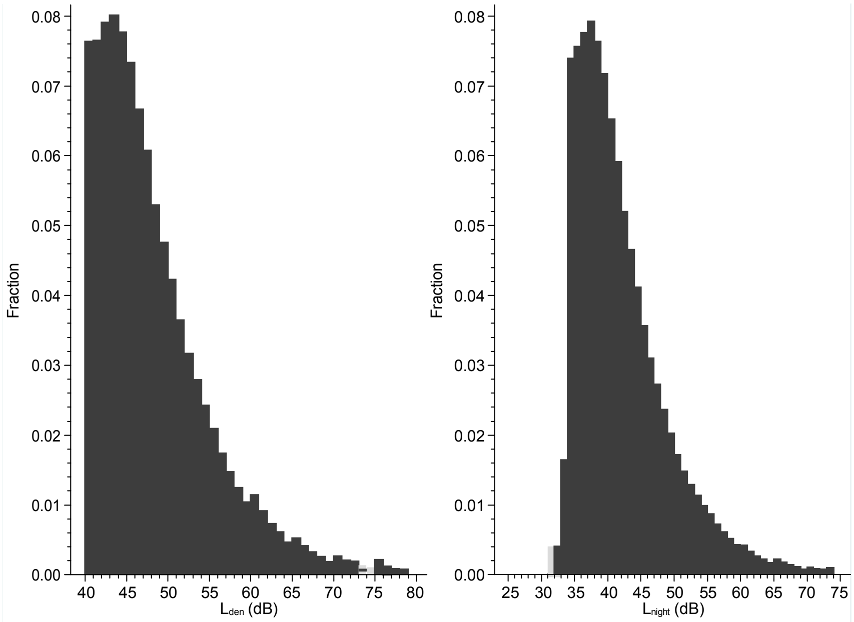

Figure 3.5: Estimated distribution for L_{den} and L_{night} within 40 dB L_{den} contour for noise from major railway outside major agglomerations

The mean L_{den} of the estimated distribution within the 40 dB L_{den} contour is 48.3 dB; the mean L_{night} 42.1 dB. The estimated mean difference between L_{den} and L_{night} is for noise from major railways 6 dB. Other statistical characteristics of the distributions are given in Annex 2.

2.7 Aircraft noise

2.7.1 Applied methods to estimate the noise exposure distribution

Compared to other sources, the dataset for aircraft noise is more difficult to impute when data from major airports or for agglomerations is missing. There have been changes in the number of aircraft movements over the years which differs between airports, so a general rule is difficult to apply. Secondly, it is difficult to assess how a change in number of aircraft movements will work out in the number of residents living within a certain noise contour. Lastly, some airports allow night flights and others not. Also curfew hours vary between airports. Night flights and the choice of the curfew hours influence the L_{den} and L_{night} distributions. This makes it difficult to extrapolate results from one airport to another airport.

Instead of following the methology of Burdett and Williams (2012), we followed another approach. RIVM commissioned in 2009 a study to Anotec Consulting S.L. to give insight in noise levels below 55 dB L_{den} and 50 dB L_{night} of major airports in Europe in 2002. Anotec had carried out a study for DG-TREN (Anotec 2003) in which the noise exposure at 51 airports in the European Union was assessed. In 2009 this study was extended to lower noise levels (40 and 30 dB) with the consequence that the linkage to the population was different than in the original study. Anotec made in 2009 use of the EU population density database, generated by the JRC which became available some years after the initial study of 2003 (Gallego et al., 2011). This database provides population density on a 100x100m grid for the whole EU. The version of aircraft noise model SONDEO (V3 rev53L) used in 2009 for the RIVM study was compatible with ECAC Doc29 3rd ed.

The results of the study are restricted. We will provide some overall results for 50 airports from 15 countries (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom). In the Anotec study no distinction was made between within and outside agglomerations. Separate cut-off points for L_{den} and L_{night} were applied (respectively 40 and 30 dB) with the consequence that the total population in both assessments do not fully comply with each other.

2.7.2 *Modelled noise exposure distribution*

In Figure 3.6 the modelled distributions for L_{den} and for L_{night} in 2002 for 50 major airports are shown as fraction of the total population within the 40 dB L_{den} contour (26 million residents) or within the 30 dB L_{night} contour (27 million residents).

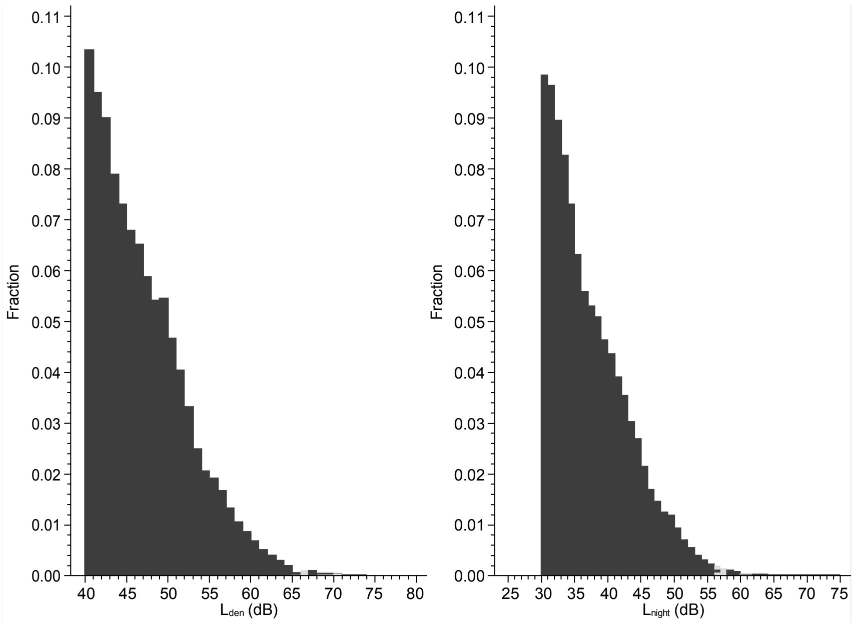

Figure 3.6: Modelled distribution for L_{den} and L_{night} within the 40 dB L_{den} contour (26.0 million residents) or within the 30 dB L_{night} contour (27.2 million residents) of 50 major airports in 2002

The mean of the modelled L_{den} distribution in the 40 dB contour is 47.0 dB; the mean L_{night} modelled in the 30 dB L_{night} contour 37.4 dB. The mean difference between L_{den} and L_{night} is 10 dB. Other statistical characteristics of the distributions are given in Annex 2.

2.8 Consequences for the number of residents in the assessments

In Table 3.5 an overview is given of the consequences of the imputation of the missing data in the END dataset and of the subsequent extrapolation of the exposure distribution to lower noise levels. Table 3.5 is restricted to the number of residents in the L_{den} assessment.

Table 3.5: Number of residents (*million) in the various L_{den} assessments, and expressed as percentage of the imputed database (≥55dB L_{den}).

	Reported (June 10, 2014) ≥55dB L_{den}		Imputed database ≥55dB L_{den}		After extrapolation to lower levels	
	#	%	#	%	#	%
Road traffic noise within major agglomerations	41	50%	82	100%	177*	216%
Noise from major roads outside agglomerations	20	87%	23	100%	125**	543%
Road traffic noise outside agglomerations and not from major roads	unknown		unknown		unknown	
Railway noise within major agglomerations	4.0	43%	9.4	100%	58**	617%
Noise from major railways outside agglomerations	3.8	54%	7.0	100%	48**	686%
Aircraft noise	-	-	2.4	100%	26***	1060%
Total (excluding aircraft noise)	69	57%	121	100%	408	337%

*Total population in major agglomerations

**Population within estimated 40 dB L_{den} contour

***Population within modelled 40 dB L_{den} contour (not END data, dated from 2002)

In the database of June 2014 the estimated completeness for road traffic noise in terms of the population living at levels large or equal to 55 dB L_{den} is 50% (40 million reported and 82 estimated after imputing the missing data). For noise from major roads, from railways in agglomerations and from railways outside agglomerations, the estimated completeness is respectively 87, 43 and 54%. For these 4 assessments together the estimated completeness is 57%. In total 69 million reported, an additional 52 million imputed leading to total of 121 million.

The extrapolation to lower noise levels leads to a total population of 408 million in the assessments for road and railway noise. This is almost 6 times larger than the 69 million original reported and more than 3 times larger than the estimated number of residents after imputation of the missing data (121 million).

We did not include aircraft noise in the totals of Table 3.5 since we did not use the END database for our assessments. Extrapolating to the 40 dB L_{den} contour leads for aircraft noise to a dataset with much more residents in the assessment (more than factor 10).

Table 3.6 is similar to Table 3.5, but addresses the L_{night} assessment.

Table 3.6: Number of residents (*million) in the various L_{night} assessments, and expressed as percentage of the imputed database (≥50dB L_{night}).

	Reported (June 10, 2014) ≥50dB L_{night}		Imputed database ≥50dB L_{night}		After extrapolation to lower levels	
	#	%	#	%	#	%
Road traffic noise within major agglomerations	28	48%	58	100%	177*	305%
Noise from major roads outside agglomerations	13	87%	15	100%	125**	833%
Road traffic noise outside agglomerations and not from major roads	unknown		unknown		unknown	
Railway noise within major agglomerations	3.0	43%	7.0	100%	58**	829%
Noise from major railways outside agglomerations	3.2	54%	5.9	100%	48**	813%
Aircraft noise	-	-	1.0	100%	27***	2564%
Total (excluding aircraft noise)	47	55%	86	100%	408	474%

*Total population in major agglomerations

**Population within estimated 40 dB L_{den} contour

***Population within modelled 30 dB L_{night} contour (not END data, dated from 2002)

The estimated completeness for the L_{night} (55%) is almost identical for the L_{den} (57%). The impact of the extrapolation to lower levels is larger than for the L_{den}. The total population of 408 million in the assessments for road and railway noise is almost 9 times larger than the 47 million original reported and almost 5 times larger than the number of residents after imputation of the missing data (86 million).

For aircraft noise, extrapolating to the 30 dB L_{night} contour has an enormous impact on the number of residents in the assessment (increase more than factor 25).

2.9 Noise exposure in relation to health based guideline levels

A first impression about the possible consequences for health and well-being of the exposure to noise can be derived when the exposure distributions are compared to health based guideline levels.

Recent health based guideline levels for the 24-hour period are not available. The World Health Organisation is currently updating the 'Guidelines for Community Noise' from 1999 (WHO, 1999); the results are not yet known. Results from recent meta-analyses (Babisch and Van Kamp, 2009; Van Kempen and Babisch, 2012; Vienneau et al, 2013; Babisch 2014) indicate that noise levels from 50-55 dB L_{den} onwards could increase the risk of hypertension and coronary heart disease. Based on these results, we used for this report 50 dB L_{den} as health based guideline value for the 24 hour period.

WHO published recently the 'Night noise guidelines for Europe' (2009). 40 dB L_{night} was recommended as guideline value. This recommended value is intended to protect the general population against sub clinical effects of night noise exposure. WHO also adopted an interim value of 55 dB L_{night}. This value is intended for situations where it is not feasible to comply on short notice with the guideline value of 40 dB L_{night}. Vulnerable groups are not protected by the interim value of 55 dB L_{night}.

From the predicted exposure distribution for road traffic noise, we estimated that 133 of the 177 million inhabitants in the major agglomerations (75% of the population) live in areas with noise levels above or equal to 50 L_{den}. For night-time noise, 145 million (82%) live above or equal 40 L_{night} and 32 million (18%) above or equal 55 L_{night}. These results are shown in Table 3.7.
Also for noise from major roads outside agglomerations, from railways and from aircrafts, we present the results in Table 3.7. For these sources the reported population and the subsequent percentages are restricted to the 40 dB L_{den} contour. Results for road traffic noise outside agglomerations and not from major roads are unfortunately unknown.

Table 3.7: Estimated size of the population (and as percentage of the population in the assessment) that is exposed to noise levels that exceed health based guideline levels for L_{den} and for L_{night}.

Noise sources and location	Estimated population in assessment (million)†	Population living at noise levels (million):		
		≥50 L_{den}	≥40 L_{night}	≥55 L_{night}
Road traffic noise within major agglomerations	177*	133 (75%)	145 (82%)	32 (18%)
Noise from major roads outside agglomerations	125**	50 (40%)	64 (51%)	8 (7%)
Road traffic noise outside agglomerations and not from major roads	unknown	unknown	unknown	unknown
Railway noise within major agglomerations	58**	19 (32%)	27 (46%)	4 (6%)
Noise from major railways outside agglomerations	48**	15 (31%)	25 (52%)	3 (6%)
Aircraft noise	26/27***	7 (26%)	8 (29%)	0.3 (1%)
Total, excluding road noise outside major agglomerations and not from major roads	-	224	269	47

† Assessed after extrapolating to lower levels (see Table 3.5 and Table 3.6)
*Total population in major agglomerations
**Population within estimated 40 dB L_{den} contour
***Population within modelled 40 dB L_{den} contour and modelled 30 dB L_{night} contour (not END data, dated from 2002)

Although it can be questioned if the results in Table 3.7 can be added since the noise exposure from different sources will partly cumulate in the same buildings, the results indicate that about 270 million residents are exposed to night-time noise exposure levels above the WHO guideline value of 40 dB L_{night}. For about 50 million European residents the interim guideline of 55 dB L_{night} is exceeded.

In Table 3.6 we estimated that in the completed END database 87 million residents (including aircraft noise) will be exposed to 50 dB L_{night} or more, while according to Table 3.7 270 million residents are at risk for night time noise. When the mandatory level in the END L_{night} assessment (50 dB) is used for risk assessment, the population at risk for night-time noise is underestimated by a factor 3.
If 50 dB L_{den} is used as health based guideline level, the mandatory level in the END L_{den} assessment (55 dB) will underestimate the population at risk by a factor of 1.8.

The largest numbers in Table 3.7 are for exposure to road traffic noise in major agglomerations. Not only in absolute numbers, but also as percentage of the population that is exposed to levels that is expected to exceed health based guideline levels.

Table 3.7 shows that 77-85% of the total size of the population that lives at levels that exceed health based guideline levels is related to noise exposure from road traffic noise (major agglomerations and major roads).

3 Health impacts assessment

3.1 Introduction

Based on the estimated noise exposure distributions (Chapter 3) we carried out a health impact assessment. The methodology is briefly described in paragraph 4.2. The results are reported according to source and location, similar to previous chapter, in paragraph 4.3 to 4.8. We rearranged the results according to health point in paragraph 4.9 to 4.11.
We also present in this chapter the results reported in 'Noise in Europe 2014' (EEA, 2014) so the differences between the results of the current and the earlier assessment based on provisional data can be compared. Be aware that these provisional results were based on the database of August 2013 and that the imputed database contains original results reported on at least July, 10 2014. So the comparison is not necessarily based on the same results.

3.2 Methodology

The details of the methods that were applied in this health impact assessment are described in Houthuijs et al. (2014). In Table 4.1 we give an overview of the health and well-being effects for which an exposure-response relation with noise is available that was based on a pooled analysis or a meta-analysis and that we applied in the health impact assessment for this report.

Table 4.1: Core characteristics of the applied exposure-response relations

Health and well-being effect	Population	Applied from	Reference
(severe) annoyance	adults	42/45 dB L_{den} and <40 dB L_{den}†	road traffic and railways: Miedema & Oudshoorn (2001); aircraft: Janssen & Vos (2009)
(severe) sleep disturbance	adults	45 dB L_{night} and <30 dB L_{night}†	road traffic and railways: Miedema & Vos (2007); aircraft: Janssen & Vos (2009)
hypertension	total population	50 dB L_{den}	road traffic and railways: Van Kempen & Babisch (2012); aircraft: Babisch & Van Kamp (2009)
coronary heart disease (mortality & morbidity)	total population	50 dB L_{den}	all sources: Vinneau et al (2013)
stroke (mortality & morbidity)	total population	50 dB L_{den}	all sources: ad-hoc meta-analysis based on 6 studies (Houthuijs et al., 2014)

† see clarification in text

The estimations for annoyance and sleep disturbance were made for sub groups of the total population (adults). For hypertension, coronary heart disease and stroke the results are reported for the total population. The results for coronary heart disease and stroke are reported in this report as hospital admissions and premature mortality due to cardiovascular disease. We have combined the effects on coronary heart disease and stroke in these two measures. We did not include the effects on cognition in this report, since an exposure-response relation is only available for aircraft noise.

For severe annoyance and for (severe) sleep disturbance a 'threshold value' for the exposure-response functions is often applied: for example 42 dB L_{den} for severe annoyance from road traffic noise and 45 dB L_{night} for (severe) sleep disturbance from railway noise. For calculations with the END data, these thresholds have no practical consequence since the lower limits of the assessment are 55 dB L_{den} and 50 dB L_{night}, levels that are well above the applied thresholds.
In this report, we extrapolated the END data to lower levels, so the application of threshold for severe annoyance and for (severe) sleep disturbance may have consequences.

For severe annoyance from road traffic and railways the problem of a 'threshold value' of 42 dB L_{den} is easy to overcome since the original functions describe that also below levels of 42 dB L_{den} a certain risk is present (see Miedema and Oudshoorn, 2001). We calculated the size of severe annoyance with and without assuming a 'threshold value' of 42 dB L_{den}.

The exposure response relations for annoyance and for severe annoyance due to aircraft noise are described for the range between 45 and 75 dB L_{den} (Janssen and de Vos, 2009). For (severe) sleep disturbance, the range is 45 to 65 dB L_{night}. At 45 dB L_{den}, the predicted percentage severe annoyance is 10%. At 45 dB L_{night}, the predicted percentage highly sleep disturbed is 17%. Given these high percentages, it is likely that below 45 dB a substantial percentage of the population is at risk for (severe) annoyance and/or severe sleep disturbance. For this reason we extrapolated the exposure response functions to lower levels. Similar, we did this for the functions for sleep disturbance in relation to night-noise from roads and railways (Miedema and Vos, 2007). Again we did the calculations with and without the assumption of a threshold of 45 dB L_{den} or 45 dB L_{den}.

The calculations for the health impact assessment were carried out per country; subsequently the results were aggregated.

3.3 Road traffic noise within major agglomerations

In Table 4.2 the outcomes of the health impact assessment are reported in the numbers of residents with a certain health or well-being effect.

Table 4.2: Affected number of residents for road traffic noise in agglomerations (177 million residents): absolute numbers of residents

Health endpoint	Noise in Europe 2014 (EEA, 2014)	Imputed database with 472 agglomerations		
		Reported and imputed ≥55dB L_{den} and ≥50 dB L_{night}	Estimated full noise exposure distribution	Full distribution & extended exposure-response
Annoyance (*million)	10.9	21.5	29.5	29.5
Severe annoyance (*million)	5.0	10.0	12.5	12.5
Sleep disturbance (*million)	4.7	9.2	15.9	17.2
Severe sleep disturbance (*million)	2.2	4.3	6.9	7.3
Hypertension (*million)	0.49	1.0	1.1	1.1
Hospital admissions (*thousand per year)	25.1	47.4	52.6	52.6
Premature mortality (*thousand per year)	5.7	11.0	12.2	12.2

In the second column of Table 4.2 we report the results of 'Noise in Europe 2014' (EEA, 2014 and Houthuijs et al., 2014). In the third column, we show the results after imputing the missing data of the END database. In this third column the results are still restricted to noise levels ≥55dB L_{den} and ≥50 dB L_{night}.

In comparison with the assessment in the Noise in Europe 2014 report based on provisional data (42.0 million residents in the health impact assessment for L_{den} and 29.6 million residents for L_{night}), the size of the health impact almost doubled for all endpoints when the imputed database was used. For examples for annoyance, the affected adults double in Table 4.2 from 10.9 to 21.5 million.

Since we are interested in the relative gain of the imputation and extrapolation processes, we made the absolute numbers from Table 4.2 relative in Table 4.3 using the imputed END database of 2012 as reference (100%).

Table 4.3: Affected number of residents for road traffic noise in agglomerations (177 million residents): relative numbers in comparison to the affected numbers in the imputed dataset (100%).

Health endpoint	Noise in Europe 2014	Imputed database with 472 agglomerations		
		Reported and imputed ≥55dB L_{den} and ≥50 dB L_{night}	Estimated full noise exposure distribution	Full distribution & extended exposure-response
Annoyance (*million)	51%	100%	137%	137%
Severe annoyance (*million)	50%	100%	125%	125%
Sleep disturbance (*million)	51%	100%	173%	187%
Severe sleep disturbance (*million)	51%	100%	160%	170%
Hypertension (*million)	49%	100%	110%	110%
Hospital admissions (*thousand per year)	53%	100%	111%	111%
Premature mortality (*thousand per year)	52%	100%	111%	111%

If we extend the health impact assessment to all 177 million residents in the agglomerations so including also noise exposure levels below 55 dB L_{den} and 50 dB L_{night} (column 4 in Table 4.2 and 4.3), the size of the annoyance increases with 37% from 21.5 to 29.5 million. For severe annoyance the rise is 25%, for sleep disturbance 73%, for highly sleep disturbed 60% and for the cardiovascular endpoints about 11%. The sharp increase in (severe) sleep disturbance is related to the relative small part of the population (32%) that is in the catchment area for the noise assessment in the framework of the END. The small increase in the size of the noise induced cardiovascular endpoints is caused by the assumption that there is no additional risk for these effects at levels below 50 dB L_{den}.

As indicated in paragraph 4.2, often thresholds for the exposure-response relations for severe annoyance and (severe) sleep disturbance are applied. In column 4 of Table 4.2 and Table 4.3 we applied the threshold value of 42 dB L_{den} for severe annoyance; in column 5 we assumed no threshold. The difference is not noticeable in the size of the impact.
In column 4 of Table 4.2 and Table 4.3 we applied the threshold value of 40 dB L_{night} for (severe) sleep disturbance annoyance; in column 5 we assumed no threshold. The size of sleep disturbance increases with another 14% from 15.9 to 17.2 million. Severe sleep disturbance rises with 10%.

The description above is illustrated by Figure 4.1 in which the results for highly annoyed, highly sleep disturbed and premature mortality are shown per decibel as the fraction of the total impact.

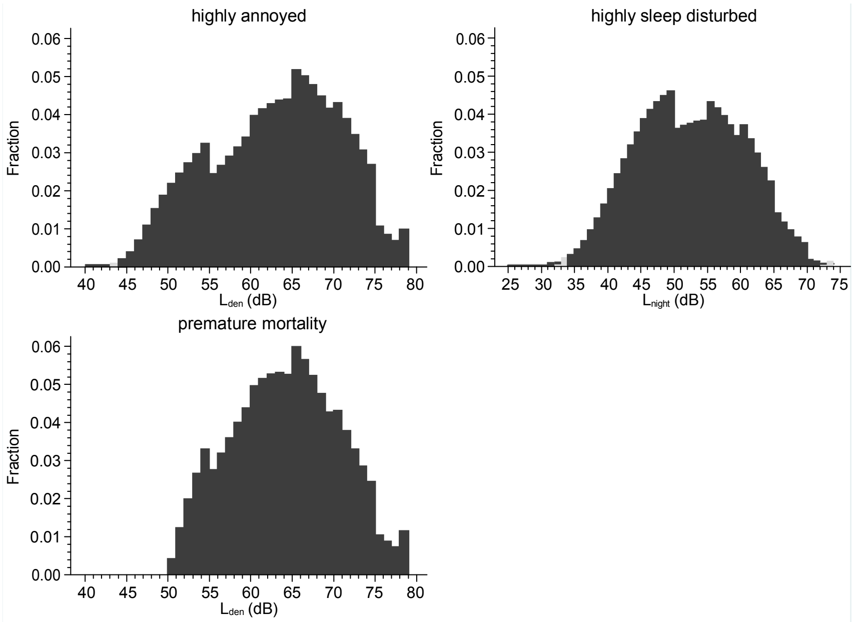

Figure 4.1: Health impact per decibel for highly annoyed, highly sleep disturbed and premature mortality, expressed as fraction of the total impact of road traffic within agglomerations.

From Figure 4.1 it becomes clear that L_{den} levels between 60 and 70 dB contribute the most to the total impact of road traffic noise in agglomerations, but that a substantial contribution can be expected from lower levels, in particular for severe annoyance. For highly sleep disturbed, the largest contribution can be expected from levels between 45 and 60 dB L_{night}.

3.4 Noise from major roads outside agglomerations

In Table 4.4 the outcomes of the health impact assessment are reported for the population living in the estimated 40 dB L_{den} contour of major roads outside agglomerations (125 million inhabitants).

Table 4.4: Affected number of residents for major roads outside agglomerations: absolute numbers of residents.

Health endpoint	Noise in Europe 2014	Imputed database		
		Reported and imputed ≥55dB L_{den} and ≥50 dB L_{night}	Estimated full noise exposure distribution	Full distribution & extended exposure-response
Annoyance (*million)	6.5	5.6	12.1	12.1
Severe annoyance (*million)	2.9	2.5	4.3	4.3
Sleep disturbance (*million)	2.7	2.5	6.0	8.4
Severe sleep disturbance (*million)	1.2	1.2	2.5	3.3
Hypertension (*million)	0.29	0.25	0.31	0.31
Hospital admissions (*thousand per year)	13.1	13.1	15.8	15.8
Premature mortality (*thousand per year)	3.2	2.8	3.4	3.4

In Table 4.5 the same results are shown relative to the 'complete' END database.

Table 4.5: Affected number of residents for major roads outside agglomerations: relative numbers in comparison to the affected numbers in the imputed dataset (100%).

Health endpoint	Noise in Europe 2014	Imputed database		
		Reported and imputed ≥55dB L_{den} and ≥50 dB L_{night}	Estimated full noise exposure distribution	Full distribution & extended exposure-response
Annoyance (*million)	116%	100%	216%	216%
Severe annoyance (*million)	116%	100%	172%	172%
Sleep disturbance (*million)	108%	100%	240%	336%
Severe sleep disturbance (*million)	100%	100%	208%	275%
Hypertension (*million)	116%	100%	124%	124%
Hospital admissions (*thousand per year)	100%	100%	121%	121%
Premature mortality (*thousand per year)	114%	100%	121%	121%

In comparison with the assessment in the 'Noise in Europe 2014' report based on provisional data (28.1 million residents in the health impact assessment for L_{den} and 17.7 million residents for L_{night}), the size of the health impact is slightly smaller (about 10% reduction, varying between 1 and 15% between endpoints) when the imputed database was used with 22.9 million residents living equal of above 55 L_{den} and 15.5 million living equal or above 50 dB L_{night}.

The affected number of residents in Table 4.5 in the imputed database of June 2014 (column 3) is lower than reported in 'Noise in Europe 2014' (column 2). This reduction is the result of a decreasing number of exposed residents in the June 2014 database compared with the Augustus 2013 database.

If we extend the health impact assessment to all 125 million residents living in the 40 dB L_{den} contour of major roads outside agglomerations, the size of the annoyance increases with 116% from 5.6 to 12.1 million adults that are expected to report annoyance. For severe annoyance the rise is 72%, for sleep disturbance 140%, for highly sleep disturbed 108% and for the cardiovascular endpoints about 21%. The clear rise in (severe) sleep disturbance is related to the relative small part of the population (12%) that is in the catchment area for the noise assessment in the framework the END. This is illustrated by Figure 4.2 in which the results for highly annoyed, highly sleep disturbed and premature mortality are shown per decibel as the fraction of the total impact.

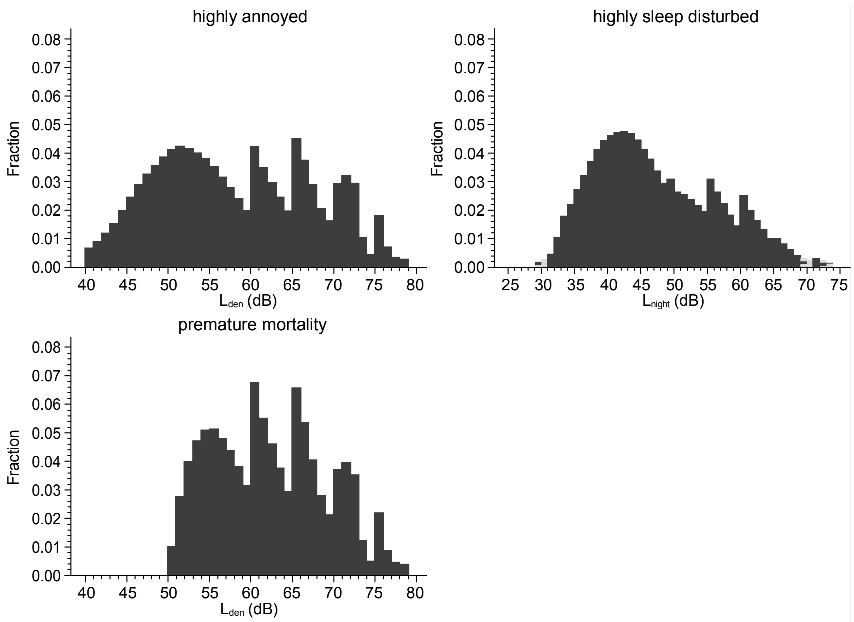

Figure 4.2: Health impact per decibel for highly annoyed, highly sleep disturbed and premature mortality, expressed as fraction of the total impact of major roads outside agglomerations.

From Figure 4.2 it appears that L_{den} levels between 50 and 55 dB L_{den} contribute the most to the total impact of severe annoyance of major roads outside agglomerations. For premature mortality, the results are a little unclear since the distribution in not well smoothed due to the assumptions made. The distribution suggest that levels round 55 dB L_{den} contribute the most, but that levels above 60 dB also put weight into the total impact.

For highly sleep disturbed, the largest contribution can be expected from levels between 40 and 45 dB L_{night}. In column 4 of the Tables 4.4 and 4.5 we applied the threshold value of 40 dB L_{night} for (severe) sleep disturbance annoyance; in column 5 we assumed no threshold. The size of sleep disturbance increased with another 96% and severe sleep disturbance with 67% indicating the influence of night-time levels below 40 dB L_{night}.
The severe annoyance at 40 dB L_{den} is limited in size. The severe sleep disturbance at the bottom of the L_{night} distribution is even smaller. These results give support to the choice to limit the assessment area for road traffic noise from major roads to the 40 dB L_{den} contour.

3.5 Road traffic noise outside agglomerations and not from major roads

Since no noise exposure distribution was available for the reporting countries (see paragraph 3.4), it was not possible to carry out a health impact assessment.

3.6 Railway noise within major agglomerations

In Table 4.6 and in Table 4.7 the outcomes of the health impact assessment are reported in absolute and in relative numbers for the population living in the 40 dB L_{den} contour of railway noise within agglomerations.

Table 4.6: Affected number of residents for railway noise within agglomerations: absolute numbers of residents.

Health endpoint	Noise in Europe 2014	Imputed database		
		Reported and imputed ≥55dB L_{den} and ≥50 dB L_{night}	Estimated full noise exposure distribution	Full distribution & extended exposure-response
Annoyance (*million)	0.63	1.5	2.8	2.8
Severe annoyance (*million)	0.23	0.53	0.78	0.80
Sleep disturbance (*million)	0.23	0.54	1.2	1.9
Severe sleep disturbance (*million)	0.087	0.21	0.43	0.62
Hypertension (*million)	0.044	0.10	0.12	0.12
Hospital admissions (*thousand per year)	2.2	5.0	5.9	5.9
Premature mortality (*thousand per year)	0.46	1.1	1.3	1.3

In Table 4.7 we report the same results as relative numbers.

Table 4.7: Affected number of residents for railway noise within agglomerations: relative numbers in comparison to the affected numbers in the imputed dataset (100%).

Health endpoint	Noise in Europe 2014	Imputed database		
		Reported and imputed ≥55dB L_{den} and ≥50 dB L_{night}	Estimated full noise exposure distribution	Full distribution & extended exposure-response
Annoyance (*million)	42%	100%	187%	187%
Severe annoyance (*million)	43%	100%	147%	151%
Sleep disturbance (*million)	43%	100%	222%	352%
Severe sleep disturbance (*million)	41%	100%	205%	295%
Hypertension (*million)	44%	100%	120%	120%
Hospital admissions (*thousand per year)	44%	100%	118%	118%
Premature mortality (*thousand per year)	42%	100%	118%	118%

In comparison with the assessment in the Noise in Europe 2014 report based on provisional data (3.9 million residents in the health impact assessment for L_{den} and 2.9 million residents for L_{night}), the size of the health impact increased more than doubled when the imputed database was used with 9.4 million residents living equal of above 55 L_{den} and 7.1 million living equal or above 50 dB L_{night}.

If we extend the health impact assessment to all 58 million residents living in the estimated 40 dB L_{den} contour of railway noise within agglomerations, the size of the annoyance increases with 87% from 1.5 to 2.8 million adults that are expected to report annoyance. For severe annoyance the rise is 47%, for sleep disturbance 122%, for highly sleep disturbed 105% and for the cardiovascular endpoints about 18%.
The clear rise in (severe) annoyance and (severe) sleep disturbance is related to large amount of residents that are living within the 40 dB L_{den} contour, but outside the catchment area for the noise assessment in the framework the END. This is illustrated by Figure 4.3 in which the results for highly annoyed, highly sleep disturbed and premature mortality are shown per decibel as the fraction of the total impact.

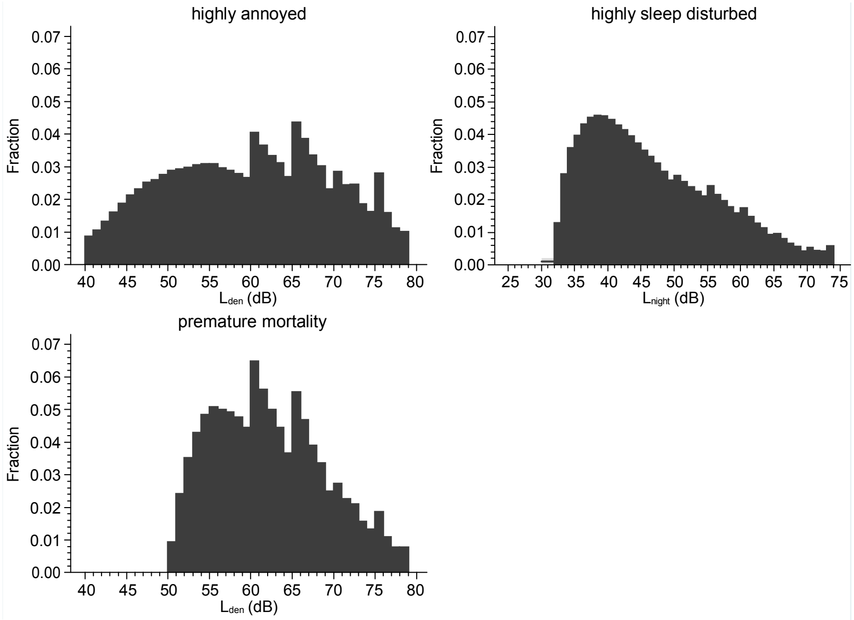

Figure 4.3: Health impact per decibel for highly annoyed, highly sleep disturbed and premature mortality, expressed as fraction of the total impact of railway noise within agglomerations.

In column 4 of the Tables 4.6 and 4.7 we applied the threshold value of 40 dB L_{night} for (severe) sleep disturbance annoyance; in column 5 we assumed no threshold. The size of sleep disturbance increased with another 130% and severe sleep disturbance with 90% indicating the influence of night-time levels below 40 dB L_{night}.

3.7 Noise from major railways outside agglomerations

In Table 4.8 (absolute numbers) and in Table 4.9 (relative numbers) the outcomes of the health impact assessment are reported for the population living in the estimated 40 dB L_{den} contour of railway noise outside agglomerations.

Table 4.8: Affected number of residents for railway noise outside agglomerations: absolute numbers of residents.

Health endpoint	Noise in Europe 2014	Imputed database		
		Reported and imputed ≥55dB L_{den} and ≥50 dB L_{night}	Estimated full noise exposure distribution	Full distribution & extended exposure-response
Annoyance (*million)	0.49	1.08	2.2	2.2
Severe annoyance (*million)	0.17	0.38	0.61	0.62
Sleep disturbance (*million)	0.16	0.46	1.2	1.7
Severe sleep disturbance (*million)	0.060	0.18	0.41	0.55
Hypertension (*million)	0.034	0.076	0.093	0.093
Hospital admissions (*thousand per year)	1.7	4.3	5.3	5.3
Premature mortality (*thousand per year)	0.37	0.85	1.0	1.0

Table 4.9: Affected number of residents for railway noise outside agglomerations: relative numbers in comparison to the affected numbers in the imputed dataset (100%).

Health endpoint	Noise in Europe 2014	Imputed database		
		Reported and imputed ≥55dB L_{den} and ≥50 dB L_{night}	Estimated full noise exposure distribution	Full distribution & extended exposure-response
Annoyance (*million)	45%	100%	204%	204%
Severe annoyance (*million)	45%	100%	161%	163%
Sleep disturbance (*million)	35%	100%	261%	370%
Severe sleep disturbance (*million)	33%	100%	228%	306%
Hypertension (*million)	45%	100%	122%	122%
Hospital admissions (*thousand per year)	40%	100%	123%	123%
Premature mortality (*thousand per year)	44%	100%	118%	118%

In comparison with the assessment in 'Noise in Europe 2014' based on provisional data (3.5 million residents in the health impact assessment for L_{den} and 2.0 million residents for L_{night}), the size of the health impact increased two to threefold when the imputed database was used with 7.0 million residents living equal of above 55 L_{den} and 5.9 million living equal or above 50 dB L_{night}.

If we extend the health impact assessment to all 48 million residents living in the 40 dB L_{den} contour of railway noise within agglomerations, the size of the annoyance increases with 104% from 1.08 to 2.2 million adults that are expected to report annoyance. For severe annoyance the rise is 61%, for sleep disturbance 161%, for highly sleep disturbed 128% and for the cardiovascular endpoints about 22%.
The clear rise in (severe) annoyance and (severe) sleep disturbance is related to large amount of residents that are living within the 40 dB L_{den} contour, but outside the catchment area for the noise assessment in the framework the END. This is illustrated by Figure 4.4 in which the results for highly annoyed, highly sleep disturbed and premature mortality are shown per decibel as the fraction of the total impact.

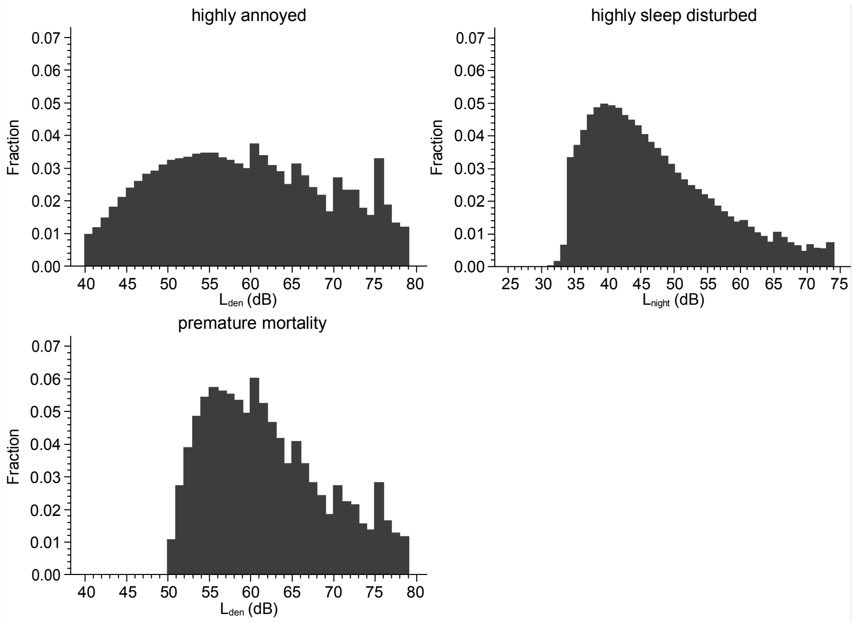

Figure 4.4: Health impact per decibel for highly annoyed, highly sleep disturbed and premature mortality, expressed as fraction of the total impact of noise from railways outside agglomerations

In column 4 of the Tables 4.8 and 4.9 we applied the threshold value of 40 dB L_{night} for (severe) sleep disturbance annoyance; in column 5 we assumed no threshold. The size of sleep disturbance increased with another 109% and severe sleep disturbance with 78% indicating the influence of night-time levels below 40 dB L_{night}.

3.8 Aircraft noise

In Table 4.10 the outcomes of the health impact assessment are reported for aircraft noise. The table is organised differently than the previous tables with results of the health impact assessment. We combined in the second column the results of the health impact assessment for noise from large airports outside agglomerations as well as aircraft noise within agglomerations (database August 2013). These results are based on 2.4 million residents living equal or above 55 40 dB L_{den} and 0.6 million resident living equal or above 50 dB L_{night}. In the subsequent columns the results for 50 major airports based on the Anotec database (assessment year 2002) are given.

Table 4.10: Affected number of residents for aircraft noise: absolute numbers of residents.

Health endpoint	Noise in Europe 2014 (within and outside agglomerations combined)	Anotec database for 2002		
		≥55dB L_{den} and ≥50 dB L_{night}	Modelled full noise exposure distribution	Full distribution & extended exposure-response
Annoyance (*million)	1.2	1.2	4.5	6.3
Severe annoyance (*million)	0.75	0.74	2.3	3.0
Sleep disturbance (*million)	0.19	0.31	0.80	4.4
Severe sleep disturbance (*million)	0.13	0.20	0.51	2.6
Hypertension (*million)	0.039	0.038	0.054	0.054
Hospital admissions (*thousand per year)	1.0	0.85	1.2	1.2
Premature mortality (*thousand per year)	0.24	0.19	0.27	0.27

Although the data is not comparable (different years, not necessarily the same airports) the results based on the Anotec database (2.4 million residents living equal of above 55 L_{den} and 1.0 million living equal or above 50 dB L_{night}) are comparable with the assessment in the Noise in Europe 2014 report based on provisional data (2.4 million residents in the health impact assessment for L_{den} and 0.6 million residents for L_{night}) with the exception of the results for sleep disturbance. This result illustrate that, due to restrictions, the exposure near the airports can differ substantial between airports for higher noise levels and that results should be extrapolated with care.

In Table 4.11 the results from Table 4.10 are made relative with the population in the Anotec dabase living above ≥55dB L_{den} or above ≥50 dB L_{night} as reference.

Table 4.11: Affected number of residents for aircraft noise: relative numbers in comparison to the affected numbers in the imputed dataset (100%).

Health endpoint	Anotec database for 2002		
	≥55dB L_{den} and ≥50 dB L_{night}	Modelled full noise exposure distribution	Full distribution & extended exposure-response
Annoyance (*million)	100%	375%	525%
Severe annoyance (*million)	100%	311%	405%
Sleep disturbance (*million)	100%	258%	1419%
Severe sleep disturbance (*million)	100%	255%	1300%
Hypertension (*million)	100%	142%	142%
Hospital admissions (*thousand per year)	100%	141%	141%
Premature mortality (*thousand per year)	100%	142%	142%

If we extrapolate the exposure-response relations and extend the health impact assessment in the Anotec database to lower levels for L_{den} and L_{night}, the size of the annoyance increases with 425% from 1.2 to 6.3 million adults that are expected to report annoyance. For severe annoyance the rise is 305%, for sleep disturbance 1319%, for highly sleep disturbed 1200% and for the cardiovascular endpoints about 41%. It is clear from these results that a substantial part of the burden of annoyance, sleep disturbance and cardiovascular health takes place just outside the area of assessment defined in the END. This is illustrated by the distribution of the health impact assessment over the noise exposure (Figure 4.5).

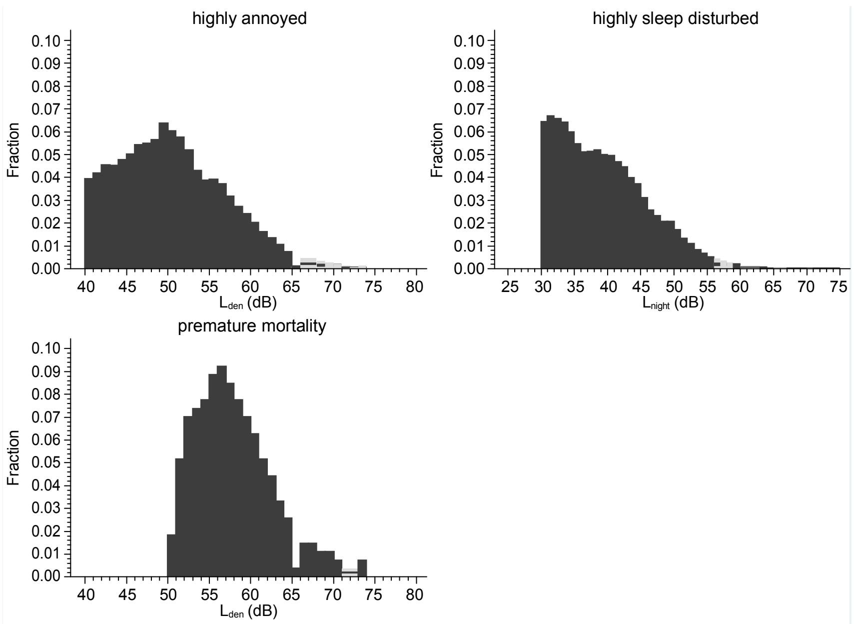

Figure 4.5: Health impact per decibel for highly annoyed, highly sleep disturbed and premature mortality, expressed as fraction of the total impact of aircraft noise.

3.9 Annoyance and severe annoyance

In Figure 4.6 and 4.7 the results are summarised for annoyance and severe annoyance by noise source and by type of assessment.

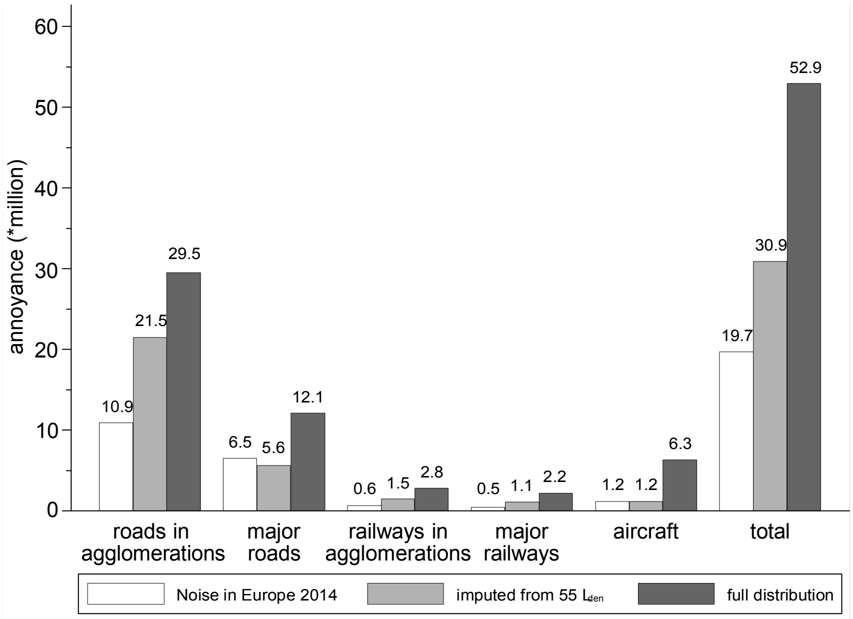

Figure 4.6: Annoyance (in million adult residents) by source and by type of assessment

Compared with the results mentioned in 'Noise in Europe 2014', the adult population with annoyance from noise from all sources increases with more than 30 million from 19.7 to 52.9 million (Figure 4.6). About 10 of the 30 million is expected to be added when the second round of noise mapping is fully completed. Another 20 million can be added if the annoyance from noise levels between 40 and 55 dB L_{den} would be taken into account.

Assuming a complete database, extrapolation to lower level will increase the size of the annoyance for all sources with 71% (from 30.9 to 52.9 million). In absolute numbers, road traffic noise adds the most to the size of the annoyance when the exposure is extrapolated to lower levels. Comparatively speaking, the increase due to road traffic noise in agglomerations is moderate (+37%), from major roads and from railway noise substantial (about +100%) and for aircraft noise enormous (+425%).

For severe annoyance the population is expected to increase from 9.1 to 21.2 million. The majority of the increase (7 million) is related to the extrapolation to lower exposure levels (+50% compared to the imputed END database).

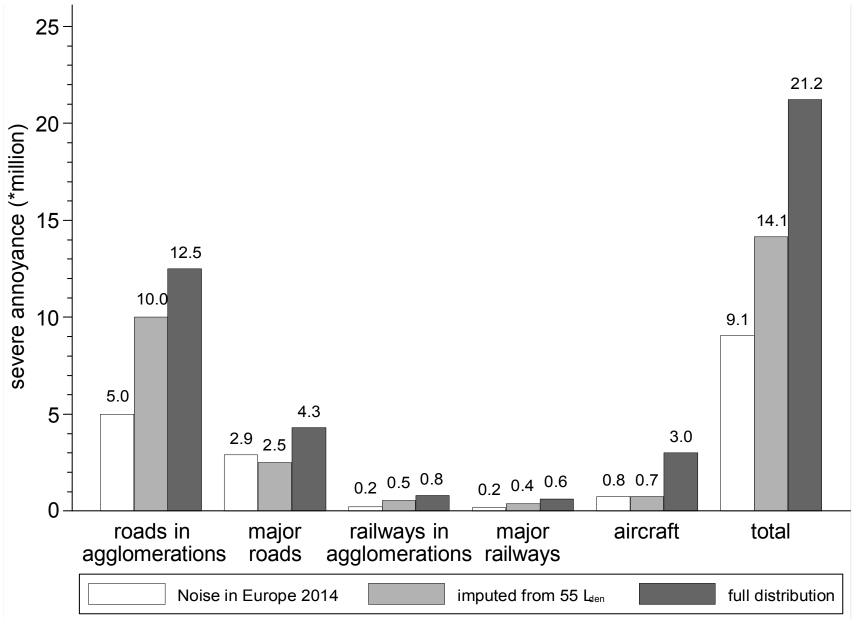

Figure 4.7: Severe annoyed (in million adult residents) by source and by type of assessment

Road traffic noise in the major agglomerations contributes the most to the size of the (severe) annoyance (59%), followed by noise from major roads (20%). Also the expected increase in severe annoyance when the assessment level would be decreased to 40 L_{den} is in absolute terms the largest for road traffic noise in the major agglomerations (2.5 million) followed by noise from major roads (1.8 million).
The largest relative increase is to be expected for aircraft noise (+300% increase), the smallest for road noise in major agglomerations (+25%).

3.10 Sleep disturbed and highly sleep disturbed

In Figure 4.8 and 4.9 the results for (highly) sleep disturbed are shown. by noise source and by type of assessment.

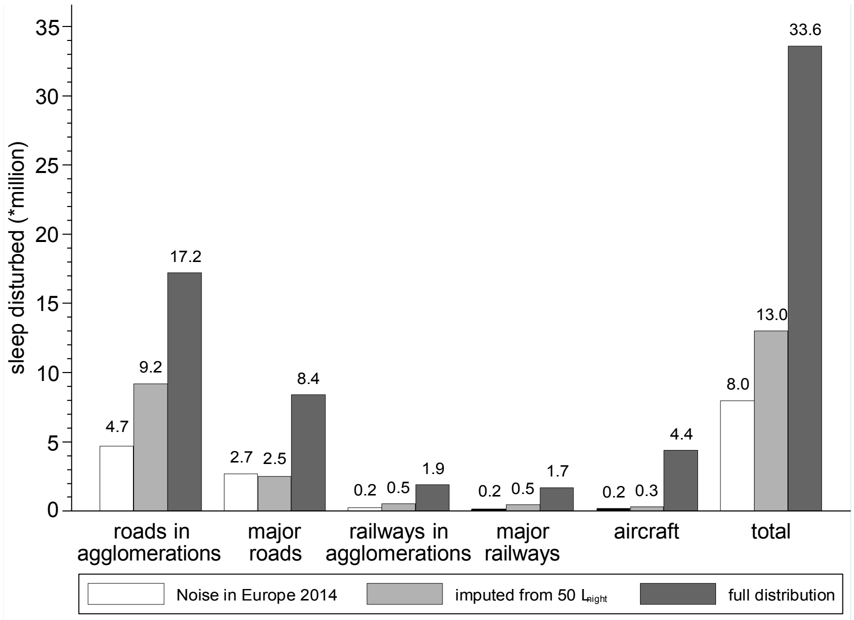

Figure 4.8: Sleep disturbed (in million adult residents) by source and by type of assessment

The results for (highly) sleep disturbed are similar to the results of (severe) annoyance, except that the extension of the assessment areas to lower levels has a much larger (relative) impact.

It is expected that a complete database of the second round will lead to 13 million adults that are sleep disturbed of which 6.1 are highly sleep disturbed. This is an increase with 5 and 2.4 million compared with the report Noise in Europe 2014.

Extension of the assessment to lower levels will lead to an additional 20 million case of sleep disturbance and 8 million cases of highly sleep disturbed. When we take the imputed END as reference, these additions are increases of 158 and 136% in the total number of residents with sleep disturbance or with severe sleep disturbance.

Road traffic noise in agglomerations had the highest absolute contribution to (severe) sleep disturbance.

The number of residents with sleep disturbance or severe sleep disturbance is, comparatively speaking, immensely underestimated for aircraft noise when 50 dB L_{night} is used as lowest level of the assessment.
Aircraft noise has the largest relative contribution (for than a factor of 10). Also for the other sources, the underestimation is a factor of about 3. The underestimation is the smallest for road traffic noise in major agglomeration; its size is still substantial (about 80%).

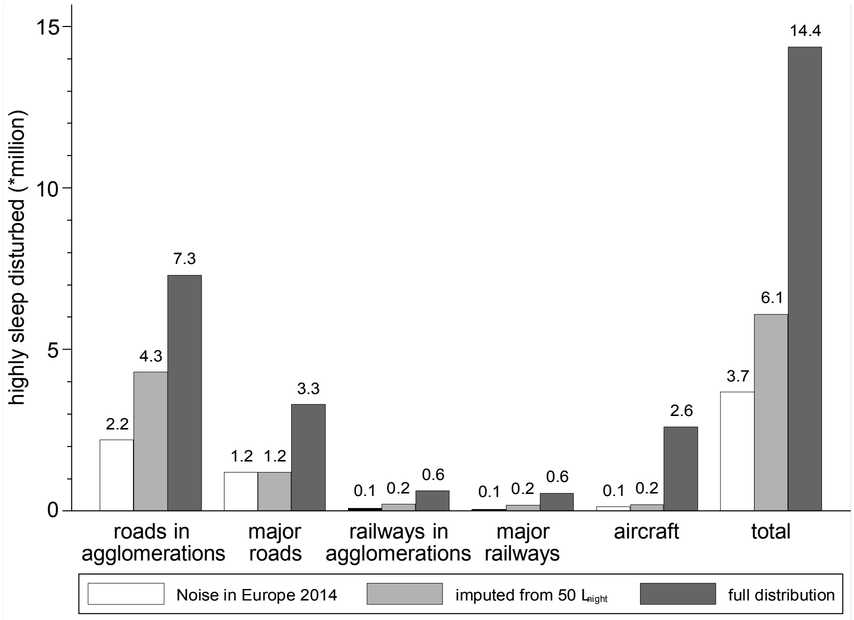

Figure 4.9: Highly sleep disturbance (in million adult residents) by source and by type of assessment

3.11 Hypertension, cardiovascular disease and premature mortality

For hypertension, cardiovascular disease and premature mortality the relative changes are almost identical. Therefore we present the results in the form of three figures (4.10 to 4.12), but we describe in the text only the results for premature mortality.

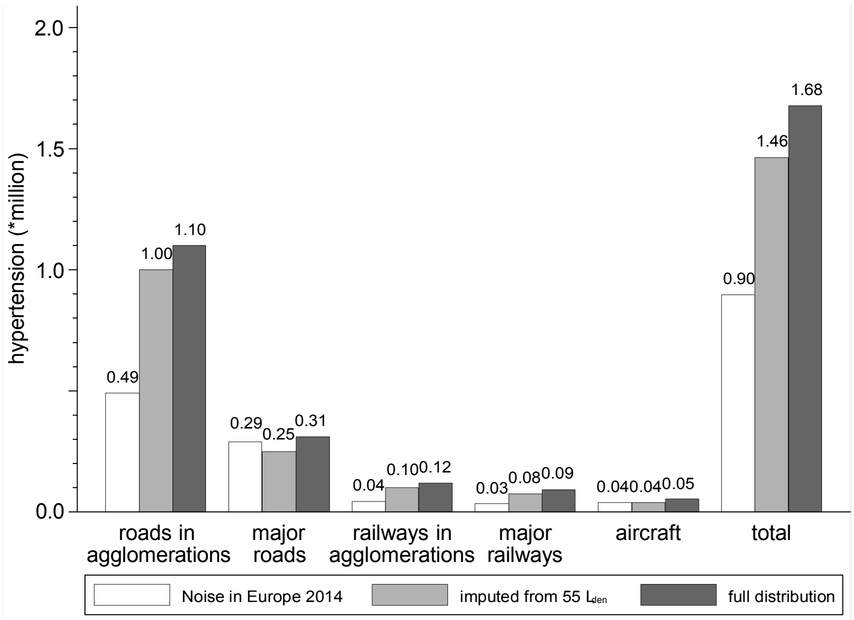

Figure 4.10: Hypertension (in million residents) by source and by type of assessment

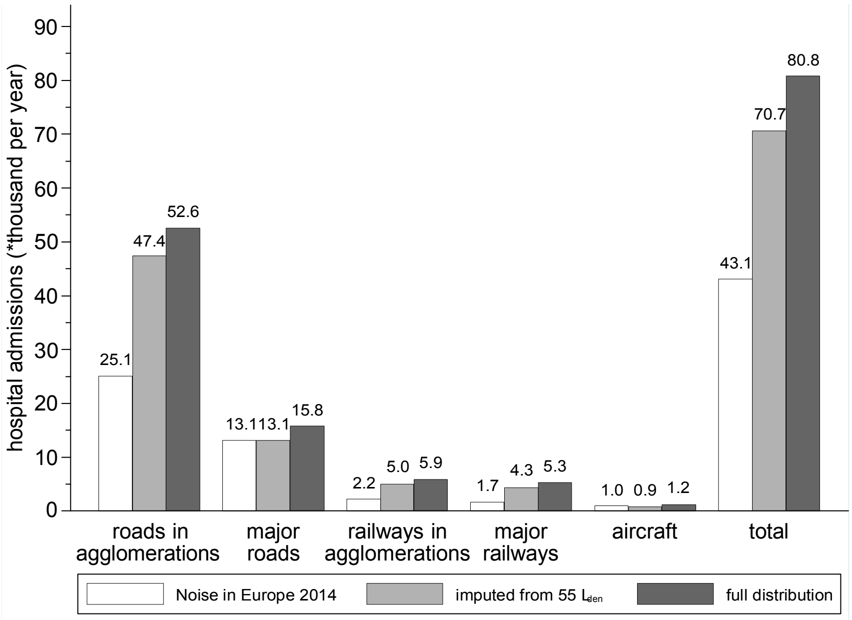

Figure 4.11: Hospital admissions for coronary heart disease and stroke (in thousands per year) by source and by type of assessment

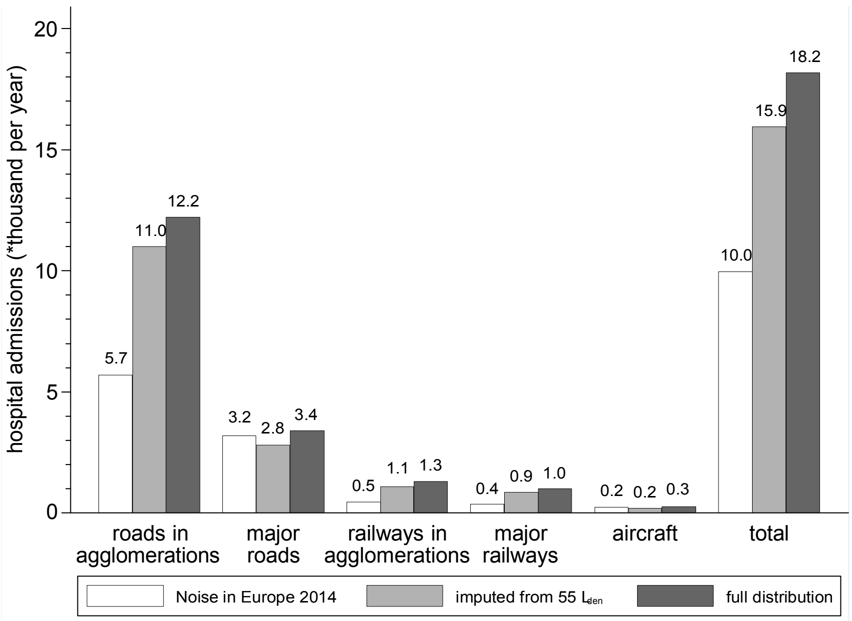

Figure 4.11: Premature mortality due to coronary heart disease and stroke (in thousands per year) by source and by type of assessment

In 'Noise in Europe 2014' it was indicated that 10 thousand cases of premature mortality per year could be related to noise exposure. If we impute the END database, this number increases to almost 16 thousand (+59%). If the complete database is extrapolated to lower noise levels, we expect 18.2 thousand cases of premature mortality per year (+14%). Since the risk for hypertension, cardiovascular disease and premature mortality are expected to rise from 50 dB L_{den} onwards, the relative increase is small in comparison with the changes that can be expected for (severe) annoyance and (severe) sleep disturbance.

Exposure to road traffic noise in large agglomerations contributes the most to the total number of cases of premature mortality (67%). The underestimation for this source is only 11%. The underestimation for the other sources is more substantial: for noise for major roads and from railways 20%, for aircraft noise 42%.

4 Discussion

4.1 Introduction

The objective of this study is to quantify some of the uncertainties in the earlier performed health impact assessment, in particular the uncertainties related to the incompleteness of the data of 2012 and the limitation of the exposure data by the requirements of END (≥55 dB L_{den} and ≥50 dB L_{night}).

We took the data reported in the framework of the END (date of the database June 10, 2014) as starting point for the health impact assessment and subsequently attempt to expand the exposure assessment to other areas in Europe not covered by the END. The discussion below relates to the total noise exposure distribution and its consequences for the health impact. The END itself is no subject in the discussion.

We did not address noise from industrial sources, since the expected health impact is relative small in relation to the health impact of the other noise sources (see Houthuijs et al., 2014) and the effort to collect information about industry noise or sources of industry noise is expected to be enormous.

4.2 Completeness and imputation of missing data

In the database used for this report (June 10, 2014) the estimated completeness for road traffic and railway noise is in total 57%; in total, the L_{den} level was reported for 69 million residents, the noise level was imputed for an additional 52 million residents leading to total of 121 million residents. The completeness varied between 43 (railways noise inside major agglomerations) and 87% (major roads).

Our basic assumptions in this first step were that the reported data in the database are valid, and that the methods described by Burdett and Williams (2012) are accurate to estimate the missing noise distributions for road traffic and railways in agglomerations and/or countries.

4.3 Extrapolation to lower levels and to other areas

In a second step, we extrapolated the noise exposure distributions for noise from roads and from railways in large agglomerations and from major roads and major railways to lower levels using information from the distributions above 55 dB L_{den}. This led to a total population of 408 million residents in the four assessments based on a population of 69 million reported in the database of June 2014 (see Table 3.5); this is a leverage of 1 to 6. In the case the database had been fully completed (estimated population of 121 million), the leverage is likely to increase to 1 to 3.

Labelling the results from this report as the 'final' results of the health impact of noise in Europe is premature. If the study would be repeated in the future using a complete database for the second round of noise assessment it can be expected that the results will differ from the

results given in this report. Given the leverage of the reported data (Table 3.5), differences between the data to be reported and our expectations about this data can have substantial effects in the future for the estimated noise exposure distributions under 55 dB L_{den}.
We therefore can conclude that an important source of uncertainty in the health impact assessment could have been avoided if more reporting states had met the date of December 30, 2012 for the reporting of second round of noise mapping.

For road traffic noise in major agglomerations, we used a statistical method to extrapolate the noise exposure distribution below 55 dB L_{den} and 50 dB L_{night}. After extrapolation, the population with noise exposure results had doubled for the L_{den} and tripled for the L_{night} in comparison with the imputed dataset (Table 3.5 and Table 3.6). Although we cannot verify the accuracy and validity of our approach, we expect that other extrapolation methods will lead to similar results. Residential areas in large agglomerations exposed to low noise levels are scarce, so the noise exposure distribution in agglomerations cannot follow many alternative shapes below 55 dB L_{den}.

For road traffic noise from major roads outside agglomerations, we extrapolated the exposure assessment to a population of 125 million living in the estimated 40 dB L_{den} contour based on Dutch data on noise exposure distributions around motorways. For the L_{den} the leverage is a factor of 5.5, for L_{night} about 8, so the applied method leads to more uncertainty than is the case for the exposure assessment for road traffic noise in agglomerations. It would be helpful to repeat this approach with data around motorways from other countries to get insight in the variability in the extrapolated results.

We were not able to estimate the road traffic noise distribution for the population outside agglomerations and not living near major roads. We could not assess any relation in the END dataset between the population density and the noise distribution. Without this relation, we were unable to predict the noise exposure distribution in other areas.
However, we did find a relation when we explored Dutch data with various grid sizes for the aggregation of the noise data. The results suggest that the surface area of the agglomerations covered by the END might be too large to find a relation between population density and the noise distribution.
We recommend a follow-up of our exploration. The results indicate that grids cell in the order of 10 to 30 square kilometres might be the proper size to predict the noise distribution for road traffic noise. There are European wide EEA reference grids available with grid resolutions of 1, 10 and 100 km. There are also databases with a European-wide coverage that could be used to study if the prediction in the grids cells can be improved. Relevant databases are the Corine land cover and road density raster datasets derived from the Global Roads Inventory Project vector dataset. If the prediction is satisfactory, this might lead to a European-wide 'road traffic noise map' that can be used in the future for health risk assessment or for a complete health impact assessment. The resolution of this map will be different than the resolution of the well-known noise maps used in the END, but its resolution might improve in future.

Another development is that modified noise modelling tools are in the making to allocate individual road traffic noise exposure to participants in large scale multi-country health studies. A recent example is the EnviroSHaPER noise modelling tool (Morley et al., in preparation). This model is based on the CNOSSOS-EU model but adjusted to use databases that are widely available with European-wide coverage, to allow for a harmonised, pan-European approach. This kind of models should be able to generate noise exposure data of sufficient quality for health studies and/or for health impact studies.

For railways noise in major agglomerations and from major roads outside agglomerations, we applied the same method for extrapolation as described for road traffic noise from major outside agglomerations. The extrapolation led to a population of 58 million residents in major agglomerations and a population of 48 million residents around major railways outside agglomeration that live in the estimated 40 dB L_{den} contour.
For the L_{den} the leverage is a factor of 6 (both assessments, see Table 3.5), for L_{night} about 8 (both assessments, see Table 3.6) so the applied method can lead to a substantial amount of uncertainty. Again, a repetition of the methodology with data from other countries would be recommended.

For aircraft noise, we did not impute the missing data of the END, nor did we extrapolate the reported noise distributions to lower levels. In 2001, ICAO recommended the concept of a 'balanced approach' to aircraft noise management. Land-use planning and management are important elements of this approach with the objective to minimise the population affected by aircraft noise around airports. The rather strict separation of functions around airports can easily lead to errors in the estimated size of exposed populations when data is imputed or extrapolated to lower levels.
Instead, we used a not public available database in which the noise levels had been modelled by one organisation up to levels as low as 40 dB L_{den} and 30 dB L_{night} for 50 major airports in Europe (situation in the year 2002) to gain insight in the contribution of lower levels to the outcomes of the health impact assessment.

4.4 Health impact assessment

The reported impact is still an underestimation since the noise exposure in areas outside major agglomerations and not influenced by major roads, major railways or major airports did not contribute to the estimations.

As indication of the population at risk for noise, it is easier to compare the estimated noise distributions with a health base guideline level than carrying out a health impact assessment.
From this comparison (paragraph 3.9) it was estimated that in total 224 million residents in Europe live at L_{den} levels which can increase the risk for cardiovascular endpoints (50 dB of above). For 269 million residents the night-time noise guideline of the WHO (40 dB L_{night}) is exceeded.
From the imputed END data, we can learn that for 122 million residents 55 dB L_{den} is exceeded and for about 85 million residents 50 dB L_{night}.

WHO is in the process of updating the 'Guidelines for Community Noise' so the chosen health based guideline levels might change in the near future. In this process some of the exposure-response relations are re-assessed using the most recent literature. Also, some new exposure-response relations might be added. The update may have consequences for the results of future health impact assessments.

The results of the health impact due to exposure to noise from roads and railways increase with about 50-80% after imputation of the missing data in the END database. These results do not come as a surprise given that the completeness of the END database varied between 43 and 87% (see paragraph 3.8).

It is expected that extrapolating noise levels from a complete database to lower levels will increase the size of annoyance with another 71% and of severe annoyance with another 50%. For the cardiovascular endpoints the influence is smaller: the burden of disease increases with 14%. For sleep disturbance the consequences are larger; about 158% more cases of sleep disturbance and 135% more cases of severe sleep disturbance. This relative high contribution of sleep disturbance at low exposure levels is a result of the relative high level of that was selected as lower limit of the noise assessment in the END (50 dB L_{night}).

The consequences of the extrapolation differ per noise source. Road traffic noise in large agglomerations contributes, in absolute numbers, the most to the increase in the size of the health impact. Comparatively speaking, the relative changes are the smallest for road traffic noise in agglomerations, and the biggest for aircraft noise.

The exposure-response relations that we used for (severe) sleep disturbance are reported for a range starting at 45 dB L_{night} (Miedema and Vos, 2007 and Janssen and Vos, 2009). We extrapolated in this report the noise exposure distributions and the exposure-response functions to levels as low as 30 dB L_{night}. It is recommended to explore if this extrapolation can be supported with results from studies into sleep disturbance at lower noise levels.

In our previous report (Houthuijs et al., 2014) we wrote that we indicated that full knowledge of the noise distribution would result in approximately 30 thousand premature deaths per year due to road, railway and aircraft noise for the total population in the EEA33. In this report we mention a total size of 18.2 million cases per year after imputation and extrapolation to lower levels: a difference of 12 thousand cases per year.
We expected at that time that a full exposure distribution for noise from major roads would lead to about 9 thousand cases per year. This is about 6 thousand cases per year more than we estimate in this report (3.4 thousand per year, see Figure 4.11). In addition, we expected about 6 thousand cases of premature mortality per year due to road traffic noise outside agglomerations and not from major roads. Unfortunately, we were not able to quantify this source in this report.

4.5 Uncertainties in the health impact assessment

A health impact assessment requires good knowledge of the causal relations between the exposure and its health effects, solid knowledge of exposure response relations and full knowledge of population exposure to noise. The results of health impact assessments often have various uncertainties and in the assessment assumptions are made that often are not explicitly mentioned. The full range of potential uncertainties in health impact assessment is for example described by Knol et al. (2009) in general and by Houthuijs and Knol (2012) for noise.

Statistical uncertainties in the exposure response relations were already quantified in the earlier report (Houthuijs et al., 2014). For this report, plausibility, reliability and robustness of data are more important than accuracy. The size of the health impact is in this case sufficient to indicate the contribution of imputing missing data and of extrapolation the data to lower levels, and to rank the impact of community noise relatively to other (environmental) agents.

It cannot be excluded that other health endpoints are related to noise exposure as well. Two recent cohort studies in Denmark investigated the risk of environmental noise on the incidence of diabetes and of breast cancer (Sørensen et al, 2013; Sørensen et al., 2014). Although the outcomes of these studies should be treated with care since the results need conformation in other studies, the findings are biologically plausible and suggest that in future health impacts assessments, additional health effects of noise may have to be considered.

Our uncertainty evaluation is far from complete. Compared with the approach described in the 'Guidance for uncertainty assessment and communication' (Petersen et al., 2013), the scope in this report is limited. Only a few issues of 'Mapping and Assessing relevant uncertainties' from the Guidance are addressed in this report. In addition, we do not address the 'Appraisal of knowledge base'. All other aspects of uncertainty are ignored like 'Problem Framing' and 'Stakeholder involvement', since we do not discuss the approach of the END or compare the current directive with other possible approaches. In Annex 3 'Appraisal of knowledge base' and in Annex 4 'Mapping and Assessing relevant uncertainties' are described in more detail.

5 Conclusions and recommendations

Preamble

We carried out a health impact assessment for noise making use of the latest available data source in which exposure data has been collected European-wide in a harmonised way: the second round of noise mapping in the framework of the END.
Health impact assessment is not an objective of the END and therefore a different application for the collected data. We quantified the underestimation related to the incompleteness of the reported data and by the limitation of the exposure data by the requirements of the END. We subsequently updated the results of the health impact assessment as reported in 'Noise in Europe 2014'.

Conclusions

The reported END data was not directly suitable for a health impact assessment. Additional efforts were required to impute missing data, and to estimate noise levels relevant for health and well-being but below the mandatory levels for L_{den} and L_{night} assessment in the END, or in areas in Europe not covered by the END.

An important source of uncertainty of this study could have been avoided if more reporting states had met the date of December 30, 2012 for the reporting of second round of noise mapping. The completeness in June 2014 was about 58%.

The health impact assessment based on an imputed and extrapolated database indicates that at least 53 million adults are annoyed due to noise from road traffic, railways or aircrafts; 21 million of them are highly annoyed. 34 Million adults are expect to experience noise related sleep disturbance; 14 million of them are severely sleep disturbed. Environmental noise exposure contributed to almost 1.7 million additional prevalent cases of hypertension in 2012, to 80 thousand additional cases each year of hospital admissions and to 18 thousand cases of premature mortality each year due to coronary heart disease and stroke. These results are an underestimation, since we were not able to assess noise levels in areas not covered by the END.

Extrapolating noise levels from the complemented END database to lower levels increased the size of sleep disturbance with 158%. For annoyance the increase is 71% and for the cardiovascular disease and mortality 14%. These results stress the importance of the contribution of lower noise levels to the health impact of community noise.

As indication of the population at risk for noise, it is easier to compare the estimated noise distributions with a health base guideline level than carrying out a health impact assessment. It is estimated that for 270 million residents in Europe the night-time noise guideline of the WHO is exceeded. The size of the population at risk for night-time noise is underestimated by a factor 3 when the mandatory level in the END L_{night}

assessment (50 dB) is used as cut-off level for risk assessment (about 87 million residents).

Recommendations

It is recommended to use at least 40 dB L_{night} (the night-time noise guideline of the WHO) as lower level of a noise assessment aimed on risk assessment or on health impact assessment.

Imputing missing data and extrapolating to lower levels lead to additional uncertainties in the health impact assessment. Alternative methods for extrapolation results to lower levels should be investigated to get insight in the uncertainty of the results.

In addition, we recommend to explore if an estimation of the health impact in Europe can be derived using other data-sources, supplementary to the END database.

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Annex 1: Extrapolation road traffic noise in agglomerations

Description
To extrapolate the exposure distribution of road traffic noise in agglomerations to lower levels, we used a statistical model based on the available data for noise levels above 55 dB L_{den} (and 50 dB L_{night}). Instead of using a deterministic statistical model, we decided to let the available data speak for itself. We used two special cases of the 4 parameter Generalized Beta distribution of the second kind (GB2). Its probability density function is:

$$GB2(y; a, b, p.q) = \frac{|a|y^{ap-1}}{b^{ap}B(p,q)(1+\left(\frac{y}{b}\right)^{a})^{p+q}}$$

The Singh–Maddala distribution is a continuous probability distribution for a non-negative random variable. It is the special case of the 4 parameter Generalized Beta distribution of the second kind when parameter p = 1; the Dagum distribution is the special case when parameter q = 1. The GB2 distribution has been shown to provide a good fit to data on income but it is suitable for describing any skewed variable and demonstrated to work out well for the noise distribution within agglomerations.

Both distributions were used to estimate the full exposure distribution per decibel within an agglomeration based on the number of exposed residents in the 5 dB L_{den} categories above 55 dB, and the remaining number of inhabitants within the agglomeration in the category below 55 dB.

A program to fit a Singh-Maddala distribution to grouped data via ML (Jenkins, 1999) was applied per agglomeration, since we expected that the distribution in each agglomeration would be different. In case the program did not converge (24 of 472 agglomerations: 5%) a Dagum distribution was applied (Jenkins, 1999) which was successful for 4 agglomerations. We assumed that no exposure below 40 dB L_{den} will take place in an agglomeration. Therefore we used the fitted distribution between 40 and 55 dB to assess the number of residents per decibel between 40 and 55 dB. For the 5 dB classes above 55 dB we also used the fitted distribution within the 5 dB class to assess the number of residents per decibel. As a consequence the numbers of inhabitants per exposure category (with a range of 15 or with a range of 5 dB) did not change in comparison with the reported numbers per agglomeration. For the remaining 20 agglomerations, we applied within each exposure category the average distribution based on the results of the 452 other agglomerations.
For L_{night} we repeated the same procedure to estimate the noise distribution between 25 and 50 dB. The application of a Singh-Maddala was successful in 465 cases; the remaining 5 agglomerations were fit with the Dagum distribution.

Source
Jenkins SP (1999) Fitting Singh-Maddala and Dagum distributions by maximum likelihood. StataTechnical Bulletin STB-48, 19–25.

Annex 2: Statistical characteristics of exposure distributions

Introduction
In Chapter 3, we estimated (or modelled) the noise exposure distributions in major agglomerations and for major roads, major railways and major airports. In this Annex some characteristics of these distributions are given.

Road traffic noise within major agglomerations

Table A2.1: Statistical distribution of L_{den} and L_{night} in 472 agglomerations (176 million inhabitants)

Mean and percentiles	L_{den}	L_{night}
mean	56.1	47.2
p5	45.5	35.5
p10	47.5	37.5
p25	49.5	41.5
p50	54.5	46.5
p75	61.5	52.5
p90	67.5	58.5
p95	70.5	61.5
p99	74.5	66.5

The estimated mean difference between L_{den} and L_{night} in the 472 agglomerations is 9 dB.

The estimated percentage of the population living between 40 and 45 dB L_{den} is about 3%, between 45 and 50 dB 22% and between 50 and 55 dB 28% of the total population. 46% Of the population lives at levels equal or above 55 dB L_{den}. For L_{night}, the estimated percentage below 30 dB is about 1%, between 30 and 35 dB 4%, between 35 and 40 dB 14%, between 40 and 45 dB 25% and between 45 and 50 dB 25%. 32% Of the population lives at levels equal or above 50 dB L_{night}. So the majority of the population in the agglomerations with more than 100,000 inhabitants live outside the noise assessment areas required for the END.

Noise from major roads outside agglomerations

Table A2.2: Statistical distribution of L_{den} and L_{night} for major roads (125 million residents within the 40 dB L_{den} contour)

Mean and percentiles	L_{den}	L_{night}
mean	49.8	41.6
p5	41.5	32.5
p10	42.5	33.5
p25	44.5	36.5
p50	48.5	40.5
p75	53.5	45.5
p90	60.5	51.5
p95	65.5	56.5
p99	71.5	63.5

The estimated mean difference between L_{den} and L_{night} is for major roads 8 dB.

The estimated percentage of the population living between 40 and 45 dB L_{den} is about 27%, between 45 and 50 dB 33% and between 50 and 55 dB 22% of the total population. 18% Of the population within the 40 dB L_{den} contour lives at levels equal or above 55 dB L_{den}. For L_{night}, the estimated percentage below 35 dB is about 16%, between 35 and 40 dB 32%, between 40 and 45 dB 26% and between 45 and 50 dB 13%. 12% Of the population within the 40 dB L_{den} contour lives at levels equal or above 50 dB L_{night}.

Railway noise within major agglomerations

Table A2.3: Statistical distribution of L_{den} and L_{night} for railway noise within major agglomerations (58 million residents)

Mean and percentiles	L_{den}	L_{night}
mean	48.6	41.2
p5	40.5	33.5
p10	41.5	33.5
p25	43.5	35.5
p50	46.5	39.5
p75	51.5	44.5
p90	58.5	51.5
p95	63.5	56.5
p99	71.5	64.5

The estimated mean difference between L_{den} and L_{night} is 7 dB.

The railway noise exposure distribution is shifted to the left. The estimated percentage of the population living between 40 and 45 dB L_{den} is about 38%, between 45 and 50 dB 30% and between 50 and 55 dB 16% of the total population. 16% Of the population within the 40 dB L_{den} contour lives at levels equal or above 55 dB L_{den}. For L_{night}, the estimated percentage below 35 dB is about 18%, between 35 and 40 dB 36%, between 40 and 45 dB 22% and between 45 and 50 dB 11%. 12% Of the population within the 40 dB L_{den} contour lives at levels equal or above 50 dB L_{night}.

Noise from major railways outside agglomerations

Table A2.4: Statistical distribution of L_{den} and L_{night} within 40 dB L_{den} contour for noise from major railway outside major agglomerations (48 million residents)

Mean and percentiles	L_{den}	L_{night}
mean	48.3	42.1
p5	40.5	34.5
p10	41.5	35.5
p25	43.5	37.5
p50	46.5	40.5
p75	51.5	45.5
p90	57.5	51.5
p95	61.5	55.5
p99	71.5	65.5

The estimated mean difference between L_{den} and L_{night} is 6 dB.

The noise exposure distribution for major railways outside agglomerations is clearly skewed to lower exposure levels. The estimated percentage of the population living between 40 and 45 dB L_{den} is about 39%, between 45 and 50 dB 30% and between 50 and 55 dB 16% of the total population. 15% Of the population within the 40 dB L_{den} contour lives at levels equal or above 55 dB L_{den}. For L_{night}, the estimated percentage below 35 dB is about 9%, between 35 and 40 dB 38%, between 40 and 45 dB 26% and between 45 and 50 dB 14%. 12% Of the population within the 40 dB L_{den} contour lives at levels equal or above 50 dB L_{night}.

Aircraft noise

Table A2.5: Statistical distribution of L_{den} and L_{night} within the 40 dB L_{den} contour (26.0 million residents) or within the 30 dB L_{night} contour (27.2 million residents) of 50 major airports in 2002

Mean and percentiles	L_{den}	L_{night}
mean	47.0	37.4
p5	40.5	30.5
p10	40.5	31.5
p25	42.5	32.5
p50	45.5	35.5
p75	50.5	40.5
p90	54.5	45.5
p95	57.5	49.5
p99	62.5	54.5

The estimated mean difference between L_{den} and L_{night} is 10 dB.

The noise exposure distribution for aircraft noise is very skewed to lower exposure levels. The percentage of the population living between 40 and 45 dB L_{den} is 44%, between 45 and 50 dB 30% and between 50 and 55 dB 17% of the total population. 9% Of the population within the 40 dB L_{den} contour lives at levels equal or above 55 dB L_{den}. For L_{night}, the percentage between 30 and 35 dB is about 44%, between 35 and 40 dB 27%, between 40 and 45 dB 18% and between 45 and 50 dB 8%. 4% Of the population within the 30 dB L_{night} contour lives at levels equal or above 50 dB L_{night}.

Annex 3: Appraisal of knowledge base

Objective
We have determined the quality of the knowledge base by establishing any limitations to our knowledge regarding its intended use. We have specified (i) the quality that is required; (ii) the current state of knowledge; and (iii) the gap between these two. In consultation with the internal and external end user(s), we have decided how any deficiencies and limitations are to be dealt with, taking into account their impact on the quality of the results, the degree to which this could be remedied, and the resources needed to do so. If the available knowledge is limited, this will be duly reflected in our report.

Relevant questions

- What ***quality criteria*** are relevant for answering the research questions?
    - These may vary per indicator/visualisation (e.g. accuracy, reliability, plausibility, scientific support, robustness).
- What policy-relevant ***controversies*** exist with regard to the knowledge base?
    - Consider controversies within the scientific arena as well as from individuals who may approach the media in an attempt to play up some uncertain issues in the knowledge base. Pay specific attention to any scientific controversies that are policy relevant.
- Are there any ***major deficiencies and/or limitations***, related to the knowledge base, to obtaining answers of the required quality, in the light of existing controversies and the strengths and weaknesses of the knowledge base? And, if so, what are these deficiencies and/or limitations?
    - Where are the crucial knowledge gaps? What are the causes (e.g. limited availability and/or quality of (a) expertise, (b) empirical data, and (c) theoretical underpinning and models)? Why are they crucial?
- What are the implications of these deficiencies and/or limitations for the scope, quality, and acceptance of the findings of this study?
    - What are the expected obstacles when 'filling' these knowledge gaps? What impact do you think these obstacles will have on the scope and quality of the study's results?
    - Could the knowledge base be improved during the study?
    - Should the knowledge base prove insufficient for obtaining answers of the required quality, then inform the end user(s) and the steering group as early as possible, and adjust the study accordingly. Document these decisions.
    - If you make assumptions to bridge a gap in knowledge, these must be explicitly stated in the report, as well as any consequences for the policy advice.
- How can these deficiencies and limitations best be addressed; either during the study or after its completion?
    - Statements on a lack of knowledge may be included in the report to help similar studies in the future. Peer review is a

useful instrument to determine whether controversies have been adequately dealt with.

Source
Guidance for Uncertainty Assessment and Communication, A.C. Petersen, P.H.M. Janssen, J.P. van der Sluijs, J.S. Risbey, J.R. Ravetz, J.A. Wardekker, H. Martinson Hughes, 2nd Edition, Netherlands Environmental Assessment Agency.

Annex 4: Mapping and assessing relevant uncertainties

Objective
We have a clear picture of (i) the relative importance of statistical uncertainty, scenario uncertainty and recognised ignorance with respect to the problem at hand; (ii) the uncertainty sources that are most relevant to the problem; and (iii) the consequences of these uncertainties for the conclusions of this study. On the basis of all this, and in consultation with internal and external end user(s), we have mapped and assessed the uncertainties and established their relevance.

Relevant questions

What are the uncertainties relevant to this problem and what is their nature and location?

How do uncertainties need to be dealt with in the study?

- The *robustness* of policy-relevant conclusions in the light of underlying uncertainties will be investigated and explicitly communicated.
- The uncertainties most relevant to policy will be identified.
  - The *possible implications* of these uncertainties will be discussed (e.g. in relation to achieving the policy targets).
  - Information will be given on the *nature* of these uncertainties (e.g. whether they are primarily caused by limited knowledge1 or stem from the unpredictable and variable nature of the system at hand2).
  - Information will be given on the possibilities of *reducing or controlling* these uncertainties and on their possible effects (e.g. Could knowledge uncertainty be reduced by gathering more knowledge in the future? Could the effects of intrinsic uncertainty be reduced by taking specific policy measures?).
- Uncertainties related to the main outcomes will be stated explicitly.
  - A quantitative description of policy-relevant uncertainties is required (e.g. ranges, outcomes of scenario studies).
  - A qualitative description of policy-relevant uncertainties will suffice.
- The main *'sources of uncertainty'* will be identified and their contribution to the overall uncertainty determined.
  - A quantitative analysis is required (e.g. on sensitivity).
  - A qualitative analysis will suffice or will be more appropriate.
- Some uncertainties are not amenable to quantitative analysis. We will employ appropriate methods to evaluate their possible roles in the analysis.

On completion of this list, you should determine whether sufficient information is available to adequately deal with uncertainties in the policy advice.

- If not, you must determine what would be required to fulfil these needs and how you will act when this cannot be fully accomplished; for example, due to a lack of resources or the presence of uncertainties or unexpected issues that cannot be fully captured (e.g. 'unknown unknowns'). In these types of cases, 'what if' gaming-simulations to explore potential consequences of the lack of information could be of benefit.

Based on the following problem characteristics, which aspects of uncertainty will require additional attention?

a) Various assumptions are critical.
    - *Be explicit about the assumptions and the framing of the study. Evaluate critical choices made. Discuss any consequences for the robustness of conclusions.*

b) The estimated indicator is close to the (legal) norm or to a (policy) target.

c) A small change in an estimated indicator may have a significant effect on estimated costs, impacts, or risks.
    - *For b and c, denote the nature of the uncertainties (e.g. knowledge limitations; intrinsic variability), how these could be analysed and discussed, in terms of accomplishing policy goals, exceeding norms, and the potential size and seriousness of effects and risks. Could uncertainty be reduced? If more research is likely to lead to an increase in some uncertainties, describe any potential policy implications.*

d) There is dissensus about policy goals.
    - *Describe the role of value-laden uncertainties and stakeholder views and interests. Discuss implications for the socio-political arena.*

e) Decision stakes are high.
    - *Describe the influence that views and values may have on both the selection of indicators and the conclusions. Discuss implications for the socio-political arena.*

f) There is dissensus about the (type of) knowledge required to solve the problem.
    - *Describe the issues on which views differ the most with respect to the (type of) knowledge required. Discuss any related impacts on the conclusion(s).*

g) Major uncertainties exist regarding the behaviour of the natural and social systems under study.
    - *Describe the consequences this has for the conclusions. Be explicit about ignorance and controversies and what these mean for the conclusions.*

h) The research method used has typical uncertainties and limitations associated with it, which require additional attention (e.g. uncertainties around model structures).
    - *Determine which uncertainties and limitations are associated with the chosen research method (measurements, models, scenarios, expert judgement).*

Where are the most important uncertainties expected to be found and what is known about their nature?

- *By using the uncertainty matrix of Annex III, the uncertainties can be classified into various types, which aids a better analysis. See Annex IIa for further information.*

- *Also pay particular attention to 'unexpected issues and unknowns'; for example, by asking 'what if' questions that force you to think outside the box and thus broaden your view of what is possible in thinking about the uncertainties. Such a question, for example, could be:*
  'Suppose that in xx years the problem would be much worse than you imagined. Could you give a plausible explanation for why things may have gone wrong? If so, does that make you want to revisit any of your previous assessments of uncertainty and confidence?'

What actions or methods would be required to better map the most important uncertainties and how feasible are they to execute, given the available resources? What uncertainty assessment activities will be carried out?

- *After application of the uncertainty matrix in Annex III, you can determine which tools are necessary for the uncertainty assessment. You may also consult various experts in the field. See Annex IIb for further advice and follow-up actions.*

Source

Guidance for Uncertainty Assessment and Communication, A.C. Petersen, P.H.M. Janssen, J.P. van der Sluijs, J.S. Risbey, J.R. Ravetz, J.A. Wardekker, H. Martinson Hughes, 2nd Edition, Netherlands Environmental Assessment Agency.