Noise in Europe 2017: updated assessment

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Executive summary

Noise pollution is a growing environmental concern. It is caused by a varied number of sources and is widely present not only in the busiest urban environments but also in natural environments. This report sets out to quantify the scale of the problem, assess what actions are being taken and proposes which ones may need to be considered in the future in order to redress the problem.

The key messages from this report are:

- Four years after the closure of the official reporting date for second round of strategic noise mapping (2012), data is still incomplete: information is missing for 14% of the agglomerations concerning road traffic noise exposure, 18% for rail traffic noise, 35% for aircraft noise and 38% for industrial noise exposure inside agglomerations. Outside agglomerations, 22% of the major airports are still missing, while around 20% of countries have not delivered information for major roads and major railways exposure.
- Estimations based on calculated figures complementing current data reported on noise exposure show that more than 100 million people could actually be exposed to road traffic noise above 55 dB L_{den}, with more than 32 million exposed to noise levels above 65 dB L_{den}.
- One in 8 persons living in cities with more than 100.000 inhabitants is exposed to night noise levels higher than 55 dB L_{night}.
- During the period 2007-2012, cities have followed different trends in relation to changes in people exposed to different noise sources. All possible patterns have been found, from exposure decrease (by different degree), no change, to increase of people exposed.
- The balance between 2007 and 2012 is a net decrease of the total population exposed to different noise sources (within the constraints of the completeness of the data). The magnitude of decrease is related to the total people exposed in 2007, therefore about 20 million of people benefit in Europe of not being exposed anymore to road traffic noise above L_{den} 55 dB. The decrease also benefits about 1,4 million of people exposed to railways, 400 000 to air traffic and 300 000 to industry. In general agglomerations above 750 000 habitants are those with a higher relative decrease of population exposed.
- In the case of major airports, a net decrease of total population exposed by 409.000 inhabitants occurred between 2007 and 2012.
- As a result of these exposures, 14,7 million adults are severely annoyed by noise, 6,1 million adults are highly sleep disturbed by noise, 72.000 hospital admissions per year and 16.600 cases per year of premature mortality, are the most accurate estimates for the health impact of environmental noise in all END assessment areas.
- The contribution of the road traffic noise to the health impact of all noise sources in the END assessment areas is now estimated on 80-85% of which about 70% occurs in the agglomerations.
- Indicative results suggest that the health impact of road traffic noise in the END assessment areas reflects 25-45% of the total burden due to road traffic noise in Europe, depending on the health effect considered.

- There are essentially two routes to noise abatement: reduction at source -through measures relating to vehicles/drivelines, tyres, road surfaces and traffic management-, and reduction of exposure of people by means of anti-propagation or insulation measures -by increasing the distance between source and receiver or hampering noise propagation by insulating buildings or constructing noise barriers-.
- Actions to tackle congestion and promote sustainable and active forms of transport (including cycling and walking) can have joint benefits for all sectors of society by helping to reduce noise pollution and their impacts on physical and mental health.

1 Introduction

In terms of defining what is meant by environmental noise, the Environmental Noise Directive (END)[1] considers noise as unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, roads traffic, rail traffic, air traffic and from sites of industrial activity. It does not apply however to noise that is caused by the exposed persons themselves, noise from domestic activities, noise created by neighbours, noise at work places or noise inside vehicles or due to military activities in military areas. (EEA, 2014).

After 15 years of implementation of the END substantial progress has been made in terms of putting noise on the agenda of Member States and taking action to reduce the noise exposure –the final aim. Moreover, END provides a common approach to avoid, prevent or reduce on a prioritised basis the harmful effects due to exposure to environmental noise. However, as already identified on the first EEA assessment (EEA, 2014), there are still significant delays on the implementation and reporting according to requirements of the Directive.

The objective of this report is to update on the state of environmental noise in Europe with the most recent information which allows for a first analysis of changes between the first phase (2007) and second phase (2012). Moreover, special efforts have been done to assess the health impact of noise exposure. In the Noise in Europe 2014 report it was identified that, although about 90% of the health impact of transport and industrial noise may be related to road traffic noise, it likely that the END assessments may reflect only 20-35% of the total impact of road traffic noise in Europe. Given the potential size of this underestimation, additional efforts have been undertaken to estimate the complete exposure distribution of road traffic noise in Europe, to be able to calculate the health impacts associated to it.

The report is structured as follows: Chapter 2, describes the data sources and methodologies used in this assessment; Chapter 3 presents the main noise exposure assessment results based upon official information reported by the EEA member countries and gap filled with estimates for missing information; Chapter 4 presents the findings of the health impact assessment, describing the latest health impact estimates associated with environmental noise exposure in Europe. In Chapter 5, the tools and processes to reduce and manage noise exposure have been explained, focusing on noise action plans and noise abatement measures being implemented. Finally, Chapter 6 presents the general observations and conclusions arising from the assessment.

[1] Directive 2002/49/EC relating to the assessment and management of environmental noise. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0049

2 Data and methodology

The assessment performed in this report is based upon information from the EEA's member countries obtained using noise modelling and measurement methods, and reported to the EEA up to 15 April 2016. The current state of knowledge on noise in Europe is largely based upon the noise mapping data related to the END, which is derived from large-scale modelling exercises at national, regional and city scales, and noise action plans information related to the END.

Where data is available, the analysis covers up to 35 countries, the 33 EEA member countries plus the Former Yugoslav Republic of Macedonia and Montenegro. This includes assessments for up to 491 urban areas, referred to as agglomerations, in which road, rail, airport and industrial noise are considered. The assessment encompasses 92 major airports, 195 416 km of major roads and 46 905 km of major railways, outside cities.

The scope of the analysis extends only to terrestrial exposure to airborne sound as it affects the human population.

2.1 Data collection and reporting

The reporting obligations set out under the END are contained in a number of provisions which have been consolidated into the Electronic Noise Data Reporting Mechanism (ENDMR) (EEA, 2012).

The ENDRM categorises the obligations that Member States have in order to fulfil the END requirements in a series of dataflows, compiling information from Member States' strategic noise maps, summaries of the action plan details and designated roads, railways airports and agglomerations at regular intervals. Competent bodies, noise limit values and noise control programmes should also be communicated to the Commission if updates occurring. The ENDRM dataflows have been summarized in the previous Noise in Europe 2014 report (EEA, 2014).

2.2 Completeness of the END data set

The completeness of the information reported under the END can be assessed by relating source data reported (identified as DF1_5 in the ENDRM) to strategic noise maps (identified as DF4_8 in the ENDRM) and to noise action plans (identified as DF7_10 in the ENDRM) respectively.

On this basis, the data set on population exposure to major noise sources in Europe can be considered much more complete for 2012 reference year than the information published in the previous Noise in Europe 2014 report (EEA, 2014). Nevertheless, after four years of the closure of the official reporting date for strategic noise maps with the whole END coverage, data is still incomplete.

Concerning noise action plans, and although a lot of information have been submitted, the completeness of this dataset could not be assessed due to how the information is currently reported under the ENDRM. An effort is being undertaken to solve this situation in view of the third round of noise mapping and action plans.

In the case of agglomerations the most complete data is provided for rail and road sources (more than 80% of agglomerations, Table 2.1). Industry and air sources are still far from being complete (data missing for about 35% of agglomerations).

Table 2.1. Noise database: completeness by noise source for 2012 reporting year (data available until 15/04/2016)

Source	Unit	Data provided	Data not applicable	Data not provided	%	Completeness based on
Agg - air	Number of agglomerations	212	168	111	**65,6**	L_{den} indicator
	Number of agglomerations	204	174	113	**64,4**	L_{night} indicator
Agg - ind	Number of agglomerations	294	18	179	**62,2**	L_{den} indicator
	Number of agglomerations	292	18	181	**61,7**	L_{night} indicator
Agg - rail	Number of agglomerations	404	2	85	**82,6**	L_{den} and L_{night}
Agg - road	Number of agglomerations	424	0	67	**86,4**	L_{den} and L_{night}
M Air	Number of major airports	72	0	20	**78,3**	L_{den} and L_{night}
M Rail	Country	24	5	6	**80,0**	L_{den} and L_{night}
M Road	Country	29	0	6	**82,9**	L_{den} and L_{night}

In the case of major road and major railways completeness', the calculation has been done at country level – even if data is provided at regional level. The completeness of exposure data related to major roads and major railways have always been an issue, as there is for the moment no obligation to specify the segments that have been considered for the data reporting. It is assumed that the reported data covers the whole infrastructure network but for the purpose of this report and to undertake the gap filling calculations, several member states were consulted in order to determine the completeness of the reported exposure data. More information can be found in ETC/ACM Working paper, 2016.

2.3 Gap filling

Given the gaps in the data provided, a gap filling analysis has been conducted in order to estimate the potential dimension of environmental noise in Europe.

The methodology is based on modelling the relationship between reference information (e.g. total population or total length of transport networks) with population exposed, derived from reported data. Additionally, when this approach had no statistical significance country averages or European averages have been applied (ETC/ACM Working paper, 2016 based on previous work done by Extrium, 2013).

The 'gap filled' dataset was used to inform the European noise exposure assessment, described in Chapter 3 and partly the health impact assessment section, dealt in Chapter 4.

2.4 Data extrapolation

A further analysis has been undertaken in order to estimate the complete noise exposure at country level, going beyond the sources and thresholds specified in the END. This information has been used to further inform the health impact assessment at country level and at European level described in Chapter 4. This analysis is mainly focused on two main aspects:

- Extrapolation of the noise exposure distribution to lower noise levels in the END assessment areas
- Extrapolation of road noise exposure distribution (as this is the source with the highest contribution to health impacts) in agglomerations with less than 100 000 inhabitants and major roads with less than 3 million vehicles per year[2], in order to estimate the exposure levels in areas not covered by the END at European level (considering all EEA member countries).

Both methodologies have also been described in the ETC/ACM Working paper, 2016 report.

2.5 Health impact assessment calculation methodologies

The WHO regional office for Europe (WHO/Europe) is currently in the process of developing the WHO Environmental Noise Guidelines for the European Region. It is expected that the new guidelines will be published in the course of 2017. A comprehensive and objective assessment of the available evidence for the health effects of noise from the scientific literature is part of this process. Since the results of WHO/Europe were not available when this report was prepared, the health impact assessment was carried out with the same methods (exposure-response relations) as applied in the Noise in Europe 2014 report.

More detail about the methods applied can be found in Houthuijs et al. (2014) and in Annex 1.

The health impact assessment provided in Chapter 4 relies, on reported and 'gap filled' data, and includes as well the estimations throughout the achievement of the most complete noise exposure distributions by including the extrapolation to lower noise levels and to the rest of areas not covered by the END.

[2]Located outside the END-agglomerations, as within agglomerations smaller roads are supposed to be included in the END mapping.

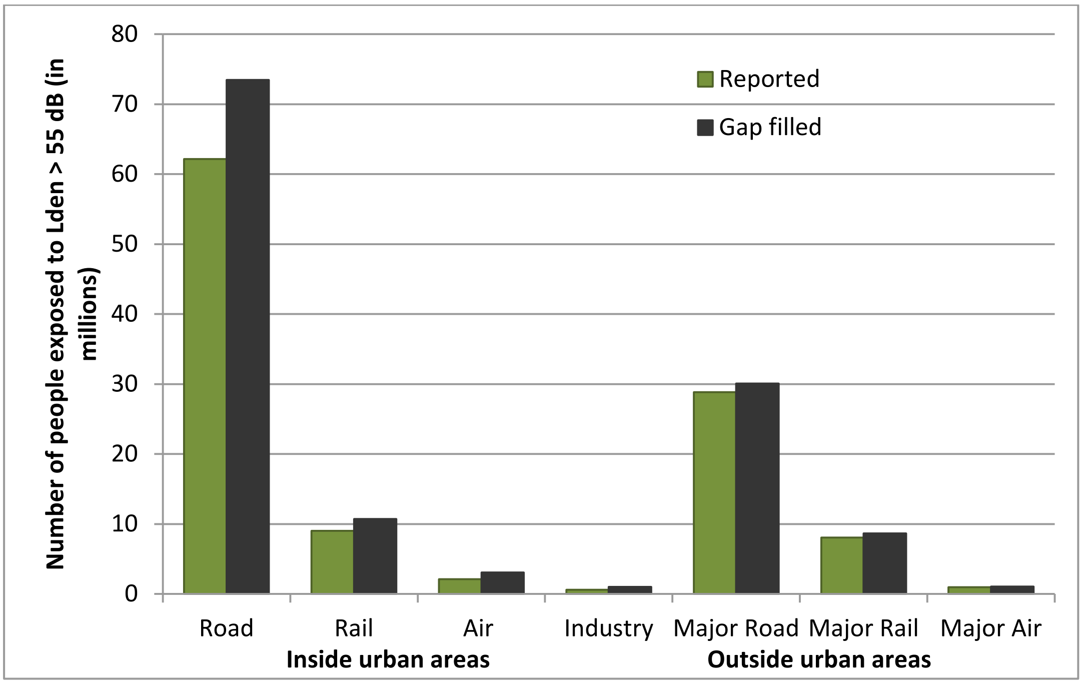
3 Exposure to environmental noise in Europe

3.1 Overall European picture

It is estimated that 525 million inhabitants are living in Europe (EEA33 excluding Turkey, and including Macedonia and Montenegro) (Eurostat, 2016), 75% of them currently live in cities (EEA, 2015). This means that nearly 400 million inhabitants live in urban areas in Europe, but only a bit more than 180 million inhabitants are covered by the END inside urban areas, representing the 45% of the total population living in cities in Europe.

Road traffic noise, both inside and outside urban areas, is still the most dominant source affecting human exposure above the action levels defined by the END, with the latest available information reported by Member States (reference year 2012). Estimations based on calculated figures complementing current data reported on noise exposure show that more than 100 million people could actually be exposed to road traffic noise above 55 dB L_{den}, with more than 32 million exposed to noise levels above 65 dB L_{den}.

Figure 3.1. Number of people exposed to noise in Europe > 55 dB L_{den} in EEA member countries (2012): reported and estimated data



As more information is being available (% of END fulfilment) estimations are less uncertain. Therefore the information on actual people exposed and potential extent with the full END coverage is improving.

Railway is the second noise source with higher number of people exposed with more than 17 million people exposed above 55 dB L_{den}. Aircraft noise with more than 3 million people exposed above 55 dB L_{den}, is the third one and finally, there is the industrial noise within urban areas with more than 600 000 people exposed above 55 dB L_{den}.

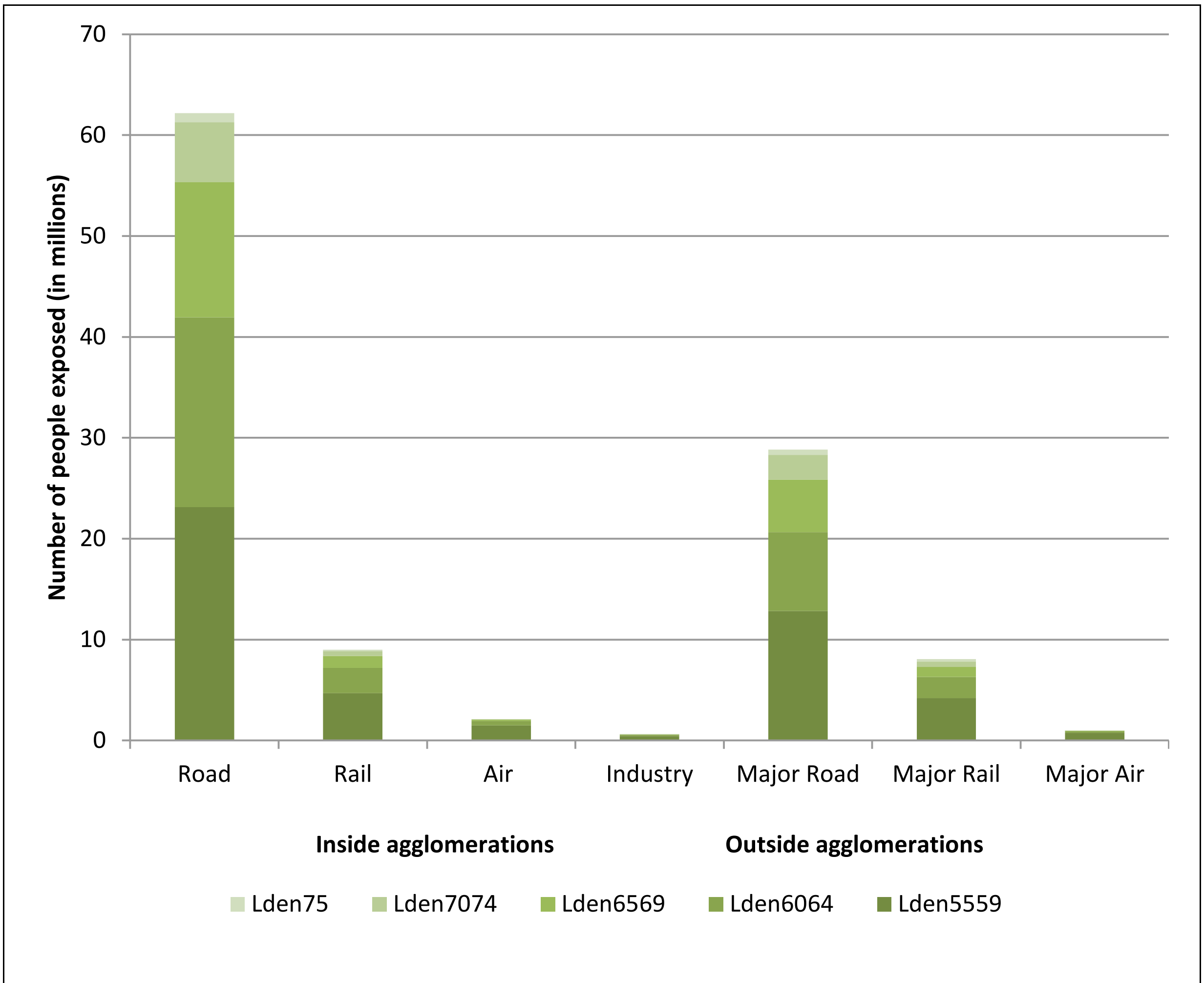
Health risks increases with higher levels of exposure, and noise abatement measures to be implemented may differ depending on the source and on the specific noise level band being addressed. Health impact assessment as well as the noise abatement measures being implemented are going to be further discussed in Chapters 4 and 5 respectively.

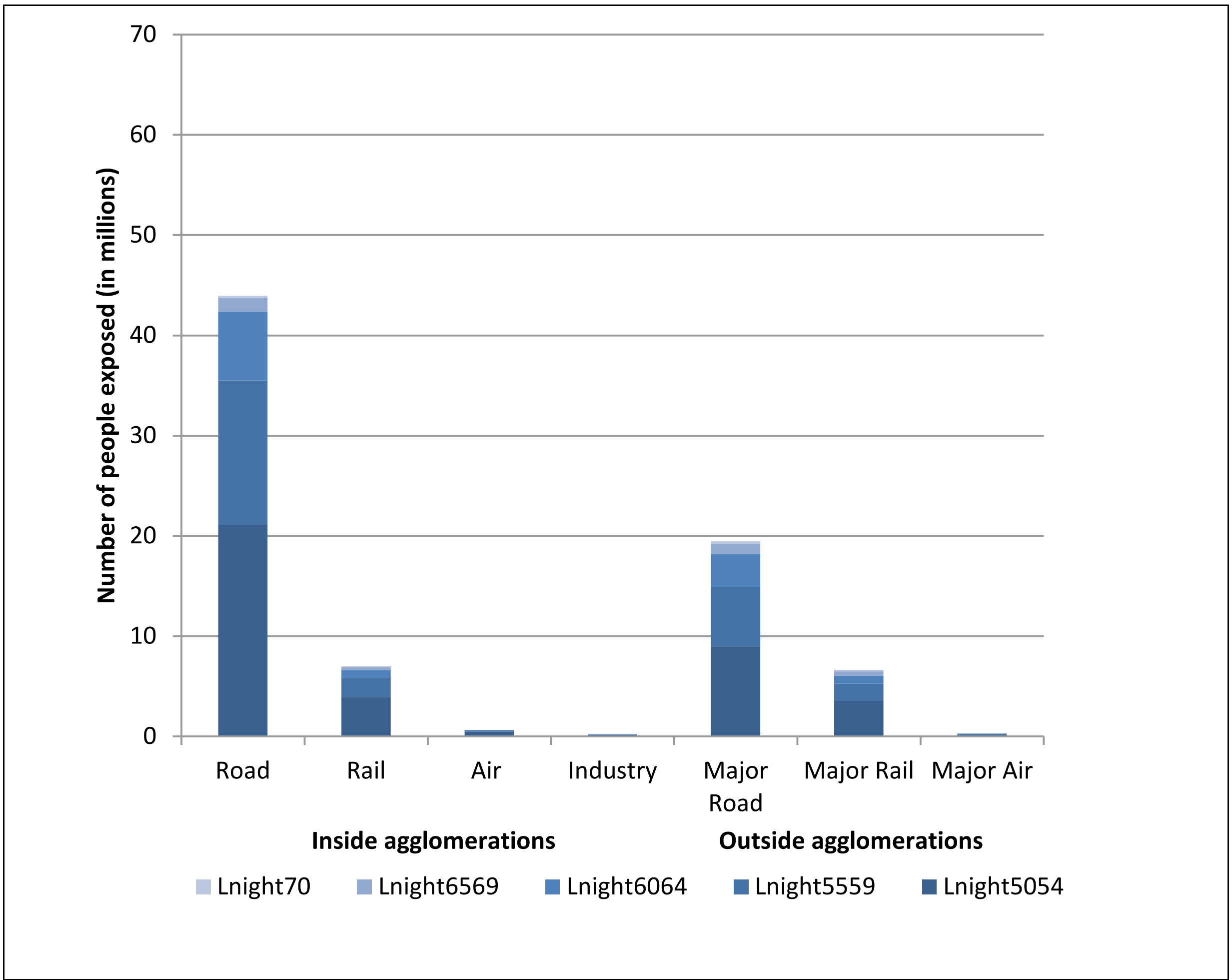
The END requires de provision of exposure information in 5 decibel bands for two indicators, to be applied in noise mapping and action planning:

- L_{den}: the day-evening-night-level indicator (designed to assess annoyance) from 55 dB
- L_{night}: the night-level indicator (designed to assess sleep disturbance) from 50 dB

The highest percentage of people reported are exposed to the lower decibel band for all noise sources, as observed in the previous assessment (EEA, 2014), and this is still the case with the new data delivered. The major difference between the lower band and the rest of noise bands is still the people exposed to aircraft noise both inside and outside urban areas, while the more balanced distribution among the population exposed to the five noise bands is the exposure to road traffic noise, both inside and outside urban areas; following the same pattern for L_{den} and L_{night} values (Figure 3.2).

Figure 3.2. Reported number of people exposed to noise per decibel band in Europe (2012): L_{den} and L_{night}



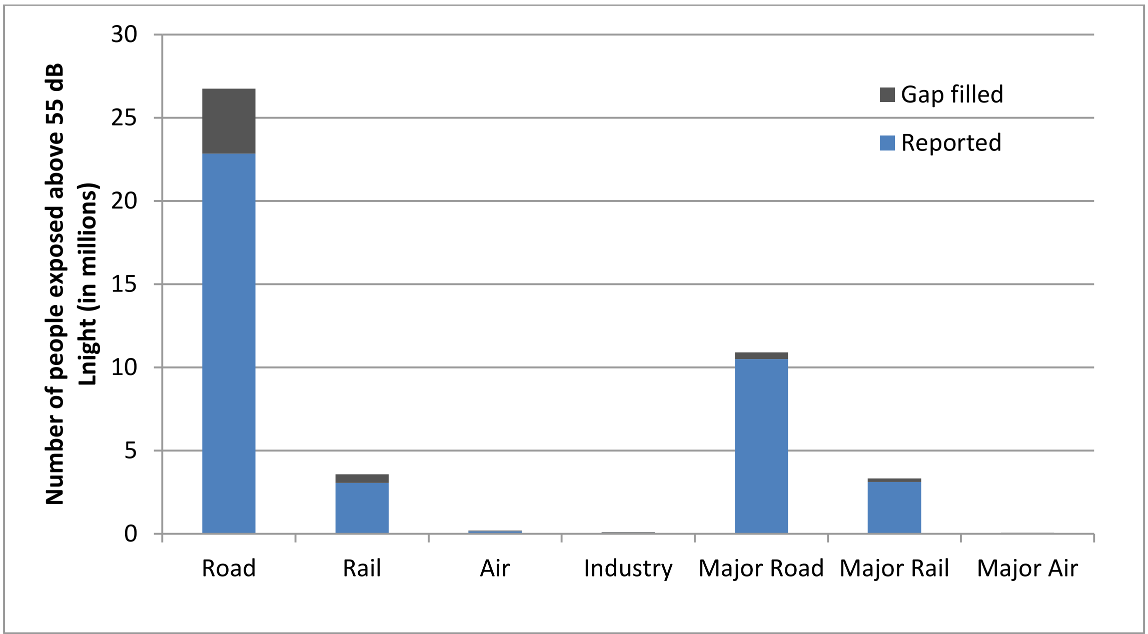


'High noise levels' are defined in the 7th EAP as noise levels above 55 dB L_{den} and 50 dB L_{night}, which are in fact the minimum noise levels at which the END requires the provision of the exposure data in 5 decibel bands. Nevertheless, the current WHO recommended limit value (under revision as December 2016) for night-time noise is set up to 40 dB L_{night} and 55 dB L_{night} as an interim target until the 40dB would be achieved (WHO, 2009).

Although the ENDRM accommodates the reporting of noise mapping exposure assessment in line with the Night Noise Guidelines level of 40 dB L_{night} on voluntary basis, only a few EEA member countries have provided these data.

So focusing on the data being requested by the END, it is estimated that more than 36 million people are exposed to more than 55 dB L_{night} in Europe due to road traffic noise, followed by nearly 7 million people exposed to more than 55 dB L_{night} in Europe due to rail traffic noise and 250.000 people and 100.000 people exposed to air traffic noise and industrial noise inside urban areas respectively (Figure 3.3).

Figure 3.3. Number of people exposed to noise in Europe > 55 dB L_{night} in EEA member countries (2012): reported and estimated data



It is known that nigh time noise disturbs normal sleep patterns and diminishes the quality of the sleep. According to the numbers reported, approximately one in 8 persons living in cities with more than 100.000 inhabitants is exposed to night noise levels higher than 55 dB L_{night}. According to WHO (2010), exposure to noise levels higher than the interim target level is dangerous for public health. Member States are encouraged to develop and implement action plans to reduce the proportion of their populations exposed to levels over the interim target (L_{night} > 55 dB) in the context of meeting wider sustainable development objectives.

Box 3.1. Which are the exposure numbers for EU-28?

By selecting the countries obliged by the European Commission to fulfil the requirements of the END, the following exposure numbers per source are being reported:

Table 3.1. Number of people exposed to L_{den} values > 55 dB for EU-28

Noise source		*Percentage of completeness*	*Reported data*	*Gap filled data*
Agglomerations	Roads	86,7	58 878 800	69 694 300
	Rails	83,0	8 386 800	10 040 400
	Aircraft	64,9	1 898 700	2 843 900
	Industry	64,1	610 900	977 700
Major roads		89,3	28 150 700	29 323 600
Major railways		84,6	7 703 100	8 267 900
Major airports		76,7	952 800	1 055 100

Table 3.2. Number of people exposed to L_{night} values > 50 dB for EU-28

Noise source		*Percentage of completeness*	*Reported data*	*Gap filled data*
Agglomerations	Roads	86,7	41 781 700	49623200
	Rails	83,0	6 488 500	7635400

Aircraft	63,5	571500	873200
Industry	63,7	225800	411500
Major roads	89,3	19062700	19825300
Major railways	84,6	6347000	6795500
Major airports	76,7	253600	266100

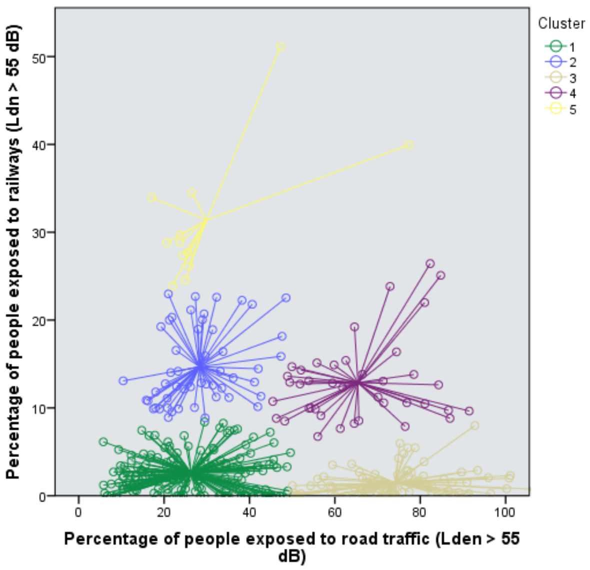
The picture obtained is very similar to the one shown when selecting all EEA member countries, and the most dominant source for environmental noise is again road traffic noise, followed by rail traffic noise, aircraft noise and industrial noise in urban areas.

Box 3.2. Can noise indicators be used to build up cities' typologies?

Five groups of cities according to the relevance of noise sources occurring inside their limits have been identified in a cluster analysis developed by ETC/ULS in 2016 (Aksoy et al., 2016). This analysis has been performed using k-means (identified as the optimal method) and take into consideration two indicators: number of people exposed to road traffic noise and number of people exposed to rail noise.

The analysis has been performed taking into considerations all cities with more than 100.000 inhabitants with data available for both noise sources (road and rail noise exposure) by 30/06/2015, without evaluating the quality of the data, the potential different methodologies applied for noise modelling in different countries and even between cities from the same country, and also the differences in the input data considered for running the model. Industrial noise exposure as well as aircraft noise exposure are highly dependent on the location of both sources in relation to the agglomeration. It has been decided to discard both noise sources from the analysis to avoid the strong biased introduced by the large number of 0 values (meaning very small number of people exposed to that noise source) or the reduction of the number of cities to be considered because any of these two sources do not exist in a specific agglomeration.

Figure 3.4. Relevance of the noise indicators on the definition of different clusters



[redacted]

The five clusters encountered can be seen in Figure 3.4, with the following characteristics to be highlighted:

- Cluster 1: largest cluster including the cities with lowest percentage of people exposed to both road noise and railway noise. Even these cities would represent those ones with highest quality of life (in the context of the cities set analysed) it should be noted that population exposed to noise from roads (L_{den} > 55 dB) is still large (average 26%).
- Cluster 2: characterized by a relatively high percentage of people exposed to railway noise (both L_{den} and L_{night}), while exposure to road is close to cluster 1 characterized by a relatively low exposure to road noise.
- Cluster 3: second largest cluster including cities with higher number of people exposed to road noise. In this cluster, half of the population is exposed to L_{night} above 50 dB but exposure to railway noise is very low.
- Cluster 4: characterized by a high exposure to road noise and also, relatively high exposure to railway noise. A common characteristic of the cities belonging to this cluster is that a high land take outside the core city occurred during the period 2006 – 2016.
- Cluster 5: smallest cluster characterized by the highest exposure to railways noise, composed by industrial cities with a high degree of soil sealing.

Figure 3.5. Spatial distribution of noise clusters in agglomerations (EEA-33)

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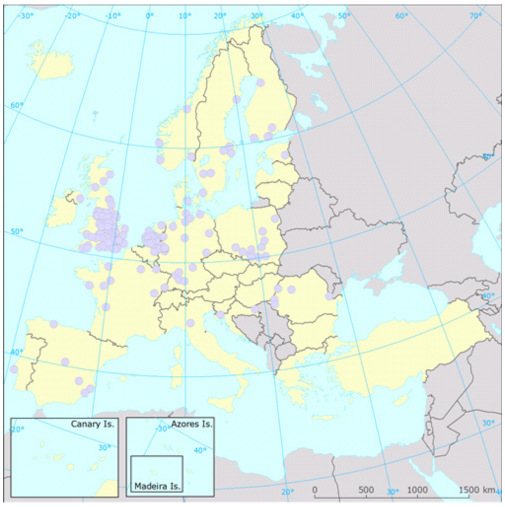
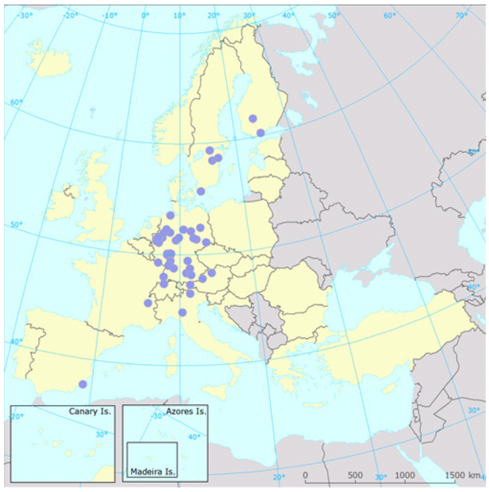
<tr><td>Cluster 1</td><td>Cluster 2</td></tr>
<tr><td>
</td><td>
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<tr><td>Cluster 3</td><td>Cluster 4</td></tr>
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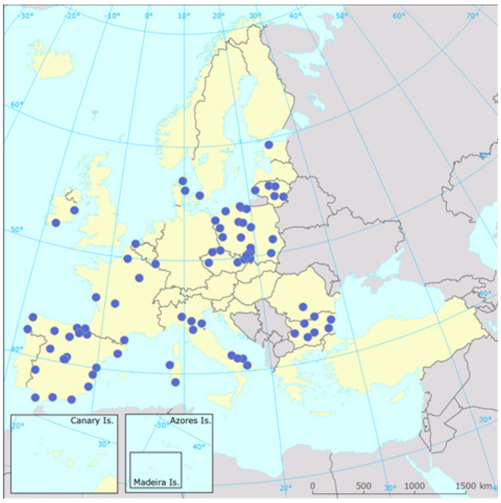
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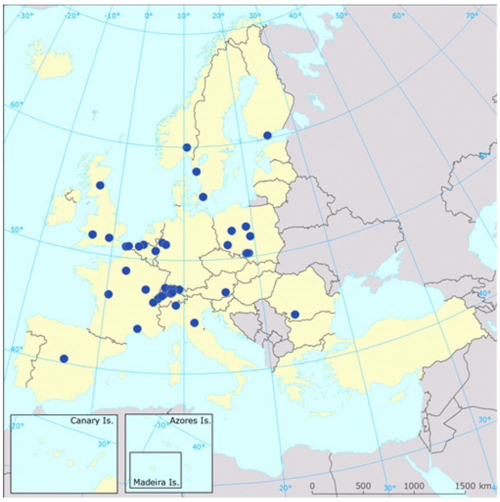
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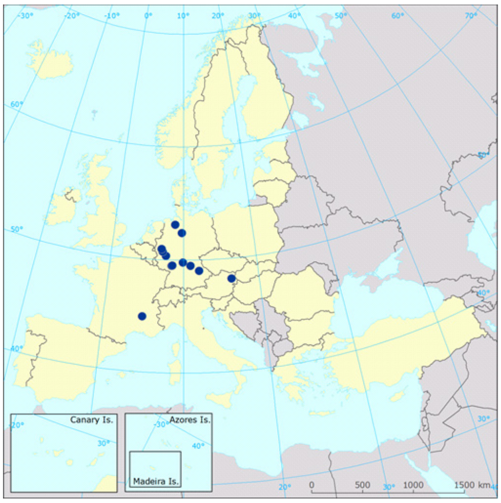
Cluster 5


Canary Is.
Azores Is.
Madeira Is.
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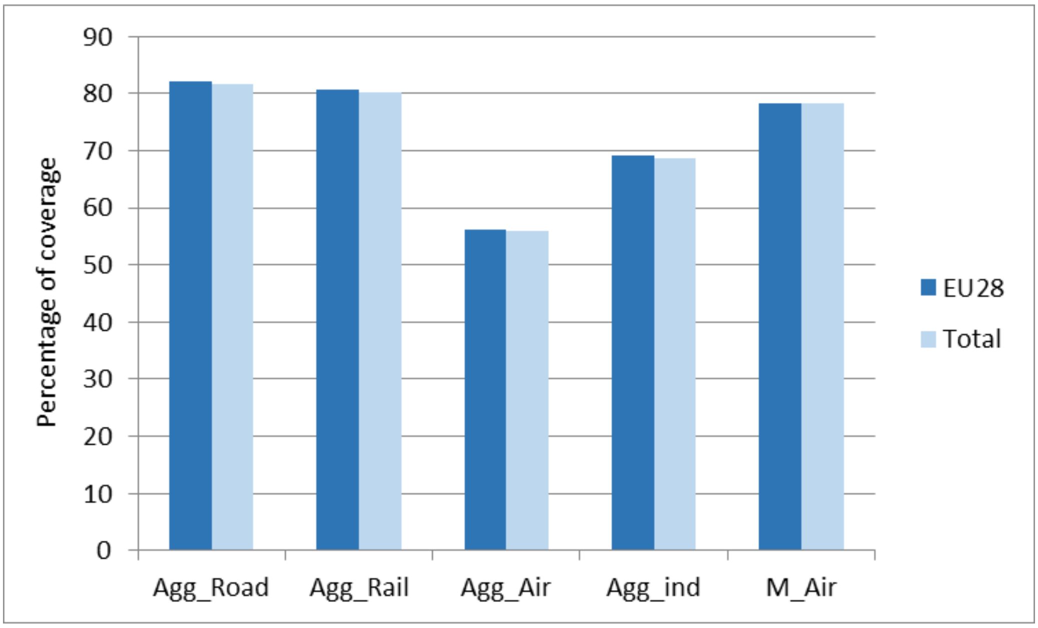
3.2 Exposure changes observed between 2007 and 2012

3.2.1 Coverage of available information

Changes on noise exposure can only be assessed on those entities where data for both reporting periods exist (i.e. 2007 and 2012). This implies that new entities that entered on the second reporting phase (2012), as consequence of enlarging the thresholds for reporting, are excluded. In the case of agglomerations, for example, only those above 250 000 have been included. In the case of major roads and major rails, since the END only requires one figure per country it is not possible to make any comparison since it is not possible to distinguish the effect of enlarging the network by decreasing the traffic threshold. Consequently this analysis focusses on agglomerations and major airports.

Data completeness, considering agglomerations where information is available for both 2007 and 2012, is around 80% regarding traffic noise and railways. However, it is substantially lower for industries and airports. In the case of major airports, almost 80% have the complete time series data.

Figure 3.6. Data completeness for analysis of changes on people exposed to different noise sources. Percentage indicates the share of agglomerations or major airports where data is available for both 2007 and 2012. Percentage is referred to number of agglomerations and major airports that had to report in 2007.



3.2.2 Overview of changes in agglomerations

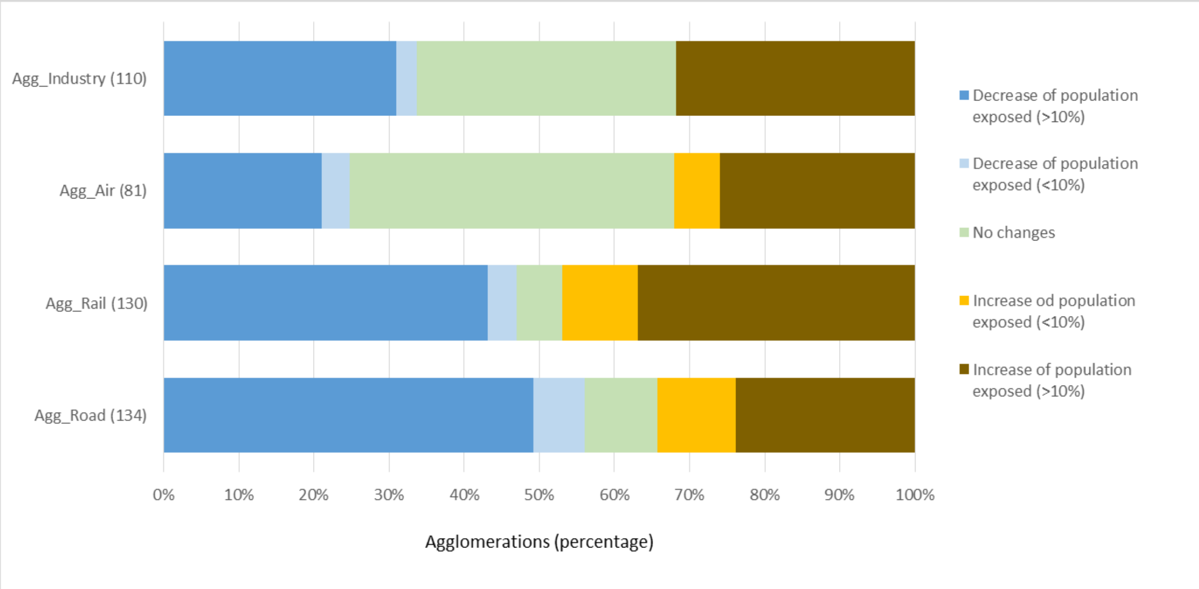
During the period 2007-2012, cities have followed different trends in relation to changes in people exposed to different noise sources (Figure 3.7). All possible patterns have been found, from exposure decrease (by different degree), no change, to increase of people exposed.

Traffic road is the noise source with a larger number of agglomerations where people exposed has decreased (55% of agglomerations). On the other side, air traffic noise is the noise source with the lower number of agglomerations with a decrease on noise exposure.

However, it should be noted that most of the cities where no change has been observed, the exposure is referred to 0 people exposed.

Considering the agglomerations where the number of people exposed is increasing, railway noise is by far the source with a major impact (47% of agglomerations). The rest of noise sources have a similar share, around 33% of agglomerations confronted with an increase on people exposed.

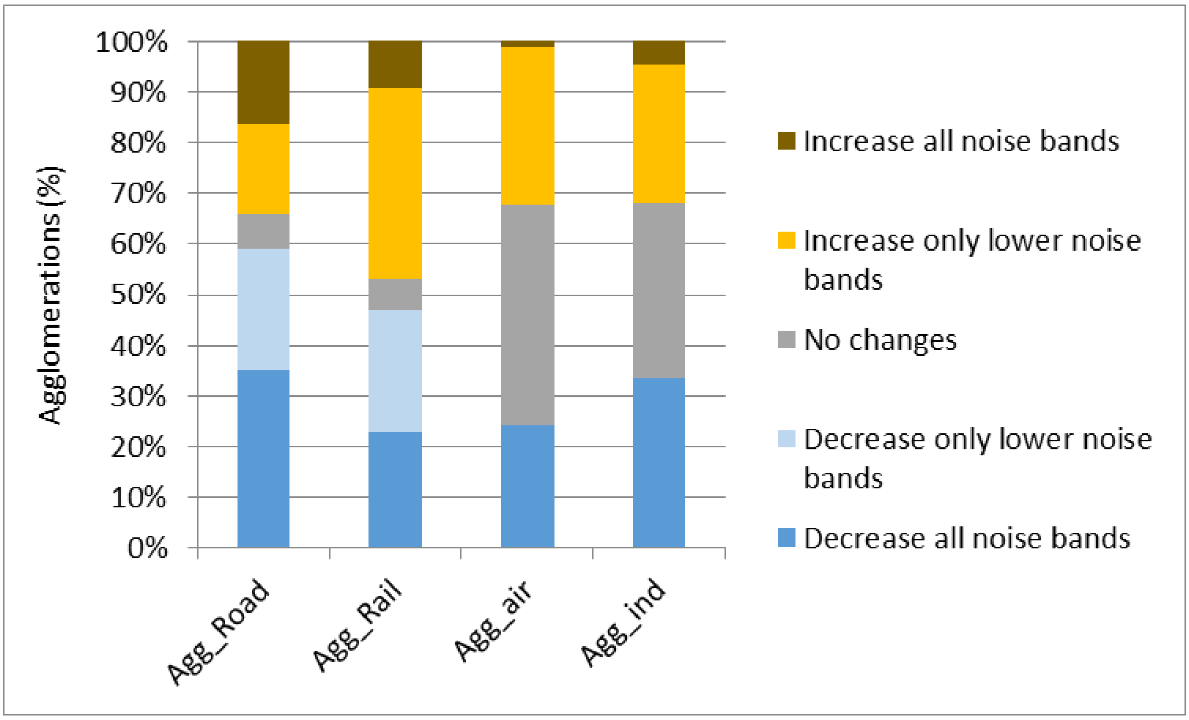
Figure 3.7. Trends on population change in agglomerations by different noise sources (2007-2012). In brackets number of agglomerations.



The impact of noise exposure is related to the dB. Therefore, noise exposure has been grouped in two noise bands: >55 L_{den} < 70 dB, and > 70 dB (Figure 3.8). It could be observed that when the people exposed to noise from traffic road has increased (2007 - 2012), about half of the agglomerations face an increase on exposure to all noise bands –including higher noise bands (15% of total agglomerations). Consequently, the impact in these agglomerations will be higher compared to the situation where the increase is only on the lower noise bands (17% of total agglomerations).

In a similar way, it could be observed that half of the agglomerations where people exposed to road or railway has decreased, this decrease is concentrated on lower noise bands.

Figure 3.8. Trends on population change in agglomerations by different noise sources (2007-2012). All noise bands refers to L_{den} > 55 dB. Lower noise bands refers to 55 > L_{den} < 70 dB



As a result of these different patterns, there is a net decrease of the total population exposed to different noise sources (considering degree of completeness of the data). The magnitude of decrease is related to the total people exposed in 2007, therefore about 20 million of people benefit in Europe of not being exposed anymore to road traffic noise above L_{den} 55 dB (Figure 3.9). The decrease also benefits about 1,4 million of people exposed to railways, 400.000 to air traffic and 300.000 to industry. In general agglomerations above 750.000 habitants are those with a higher relative decrease of population exposed.

Comparing the percentages of decrease on people exposed, industry is the noise source with higher impact (35% compared to people exposed in 2007 - 300.000 inhabitants). Road traffic noise is the second source with higher reduction on exposure (33%), while air traffic and railway are far beyond (about 20%).

The overall decrease on people exposed can be attributed to multiple causes:

- Changes in the total population of the agglomeration. Most of the cities face changes in total population as a natural process of their own dynamics. There is a population decrease in 20% of the agglomerations, while there is an increase of total population in 38% of the cities. However, there is not a significant correlation between changes in total population and changes on people exposed. This may be explained because the spatial dimension is not captured with the aggregated figures at agglomeration level. Changes in total population are not equally distributed in all neighbourhoods and, consequently do not necessarily follow the same pattern as population exposed.
- Crisis. It has been widely reported the decrease of economic activity and traffic because the economic crisis, which in turn may have reduced the levels of noise. (INRIX, 2016).

- Implementation of noise abatement measures. At current stage it is not possible to establish a direct link or to assess the impact of noise action plans on the reduction of people exposed, although it is expected that with the implementation of some abatement measures from 2009, and improvement of the noise situation would be occurring gradually.

Figure 3.9. Changes on people exposed by different noise sources in agglomerations (2007-2012)

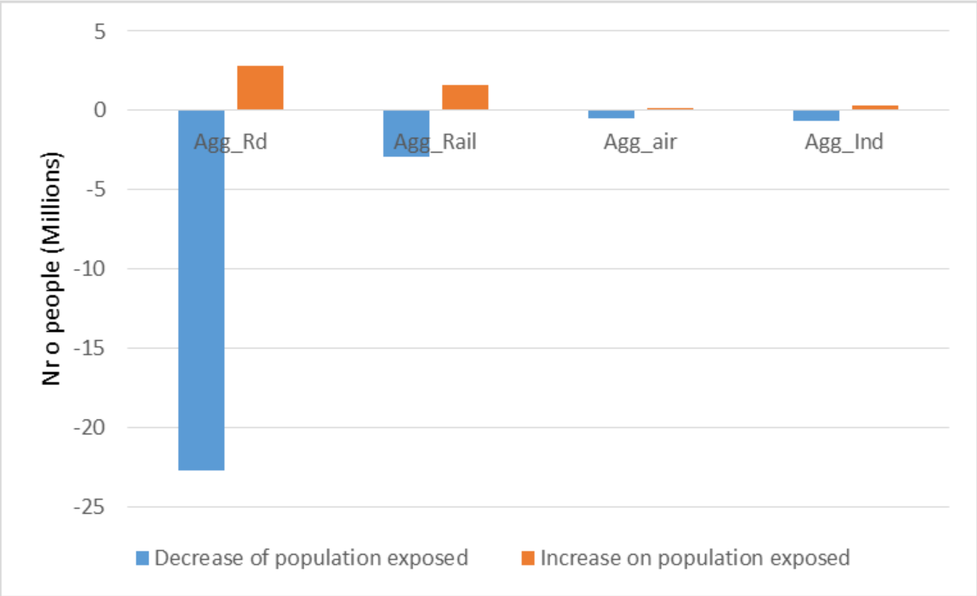
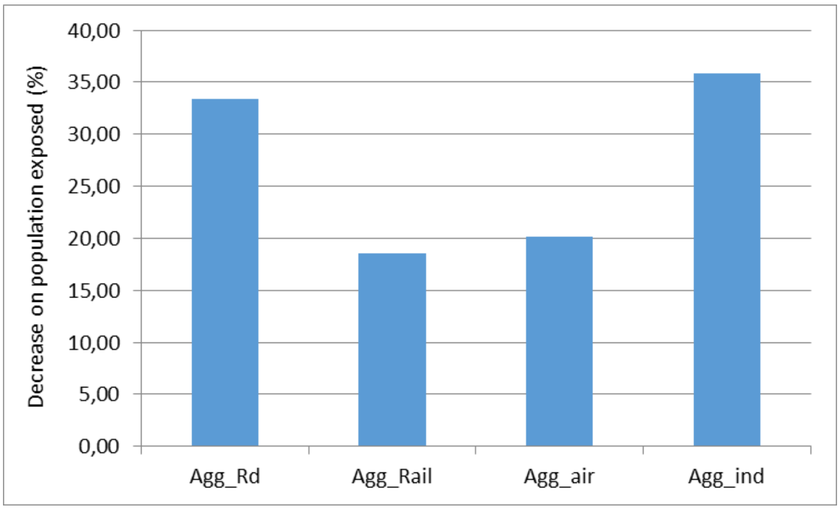


Figure 3.10. Percentage of decrease on noise exposure in agglomerations by different noise sources (2007-2012)



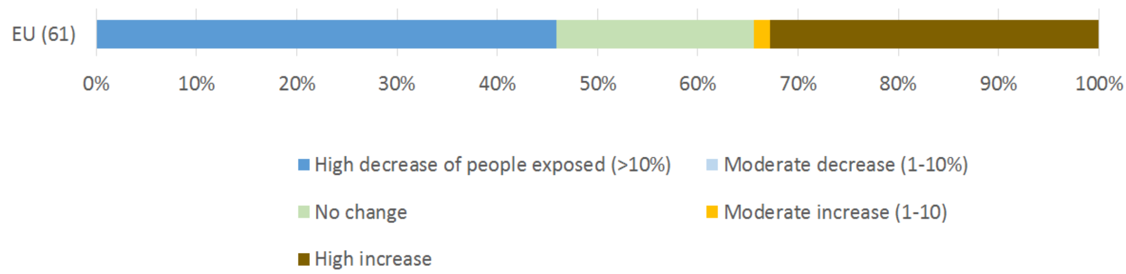
3.2.3 Major airports

During the period 2007-2012, major airports have followed different trends in relation to changes in people exposed inside agglomerations (Figure 3.11). All possible patterns have been found, from exposure decrease (by different degree), no change, to increase of people exposed. However, the percentage of airports with a decrease of population exposed (45%) is higher than those airports that faced an increase (35%).

Those changes were not related at all to changes on the traffic movements.

As a result there has been a net decrease of total population exposed by 409.000 inhabitants.

Figure 3.11. Trends on population exposed to major airports (2007-2015). Percentage refers to share of major airports.



3.3 Extrapolation to the full European coverage

The END directive has a wide appliance. Large parts of the territory of the EU member states are covered by the noise maps of the END directive (and also EEA member countries on voluntary basis). However, for some areas, this information is not available. Situations where this applies are agglomerations with less than 100 000 inhabitants and major roads with less than 3 million vehicles per year.

So, an extrapolation to the full European coverage was carried out focused on exposure to road traffic noise, to serve as input for the health impact assessment. The calculations for the health impact assessment were carried out for 32 countries (EU28, Iceland, Liechtenstein, Norway and Switzerland) and were done on a country level. Subsequently the results (and calculations) of the extrapolated noise assessment were also aggregated per country and were carried out for the same 32 countries.

In a first step, the reported and gap-filled data for road traffic noise inside agglomerations and for major roads outside agglomerations have been extrapolated to lower noise levels using information from the distributions above 55 dB L_{den}. This resulted in a figure of 128 million people exposed to road noise inside agglomerations above 50 dB L_{den} (160 million residents above 40 dB L_{night}) and 55 million people exposed to major road noise outside agglomerations above 50 dB L_{den} (67 million residents above 40 dB L_{night}).

The second step was to estimate the full exposure distribution per decibel for road traffic noise within agglomerations, 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 L_{den}. More information on the statistical model being used can be found in ETC/ACM Working paper, 2016.

In a third step, a methodology was developed to estimate the road noise exposure distribution in areas not covered by the END. This methodology makes use of the association between population density and the noise exposure level. This association has been recognized about 40 years ago (Galloway et all, 1974). By using the relationship between population density and exposure distribution from the Netherlands (RIVM 2011) and from Switzerland (BAFU 2015) and subsequently applying it to the rest of countries, an estimated number of people

exposed to road traffic noise per each country has been encountered. By adding this information to the number of people exposed to major roads outside agglomerations, almost 230 million people are exposed to road traffic noise above 50 dB L_{den} and 261 million residents are exposed above 40 dB L_{night}.

It has been deliberately chosen to report the exposed population in terms of exceeding 50 dB L_{den} and for night time exposure, in terms of exceeding 40 dB L_{night}, as the night time noise guideline of the WHO is currently indicating.

The combination of the different calculations and steps give a total exposed population of 357 million inhabitants above 50 dB L_{den} (of which 206 are exposed above 55 dB L_{den}) and for the night time exposure, a total of 421 million inhabitants are exposed above 40 dB L_{night} due to road traffic noise.

Taking into account that the total number of inhabitants in all Europe (EEA 32 member countries being considered, and Macedonia and Montenegro) is estimated to be 525 million people, nearly 7 out of 10 people living in Europe are exposed to noise levels above 50 dB L_{den}, and approximately 4 out of 5 residents are exposed to night noise levels above 40 dB.

Table 3.3. Combined results for estimation of exposure to road traffic noise (total population is 525 million)

	Population(million) ≥40dBLnight*	*Population(* million) ≥50dBLden*	*Population(*million) ≥55dBLden*	*Perc. population in database (above 50 dB L_{den})*
Extrapolated and gap filled END-data for major roads outside agglomerations	67	55	30	-
Grid-approach (results based on mean distribution CH/NL noise exposure)	237	199	105	-
Combined results major roads and grid approach	**261**	**229**	**133**	**65**
Extrapolated and gap filled END-data for road traffic in agglomerations	**160**	**128**	**73**	**35**
Total exposure for road traffic noise	**421**	**356**	**206**	**100**

4 Impacts of noise exposure – health impact assessment

The assessment was carried out for 32 countries (EU28, Iceland, Liechtenstein, Norway and Switzerland). The results presented are aggregates of the results for these countries. The health and well-being endpoints considered were annoyance, sleep disturbance, cognitive performance, hypertension and cardiovascular and cerebrovascular disease and mortality.

4.1 Annoyance and sleep disturbance

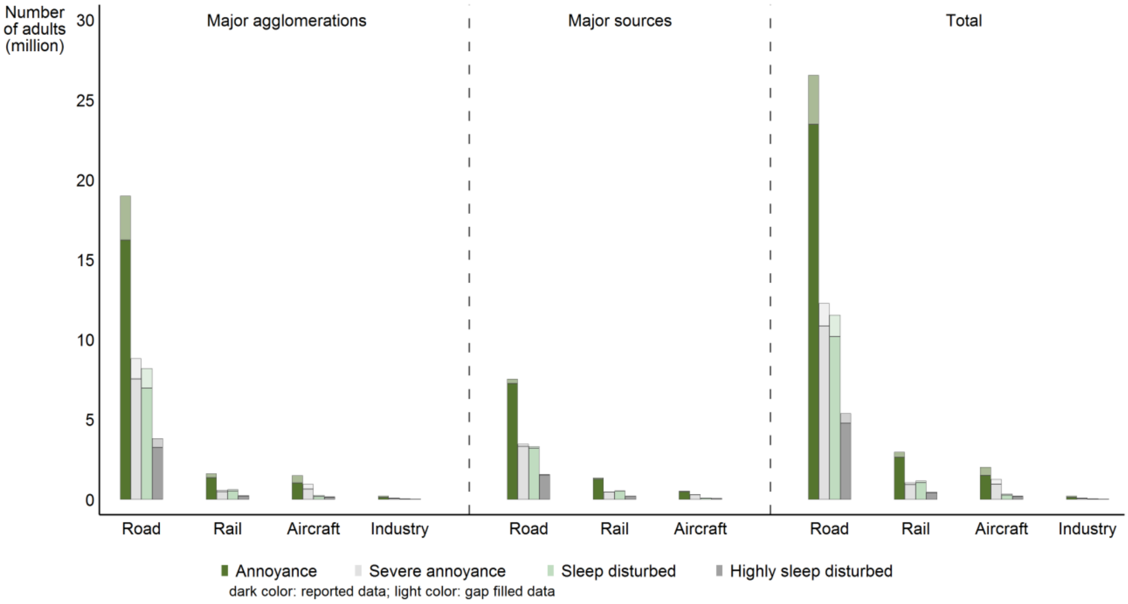
Based on the noise data reported by countries for 2012, around 27,6 million adults living in agglomerations or near major sources with noise levels equal to or above 55 dB L_{den} may be considered as being ‘annoyed’ by noise from road traffic, railways, aircrafts or industry; 12,8 million of them are ‘severely’ annoyed.

Adding the gap filled END data increases the total number of adults being annoyed by noise to around 31,7 million. 14,7 million of them are ‘severely’ annoyed.

Similar, it was assessed that 11,5 million adults have sleep disturbance due to night time noise levels equal to or above 50 dB L_{nigh}t from road traffic, railways, aircrafts or industry. About 5,3 million of them are highly sleep disturbed. Supplementing the reported END data with gap filled data, the impact is enlarged to 13,1 million adults with sleep disturbance. 6,1 million of them are highly sleep disturbed.

In Figure 4.1, the results for annoyance and sleep disturbance based on the reported and gap filled END data are presented according to the noise source and the location of the assessment.

Figure 4.1. Estimated number of adults with (severe) annoyance and estimated number of adults that are (highly) sleep disturbed according to the noise source and location of the assessment, based on the reported and gap filled END data



As shown in the figure based on the reported and gap filled END data, about 85% of the burden of annoyance and sleep disturbance is related to road traffic noise, of which about 70% occurs in the agglomerations.

4.2 Reading impairment, hypertension, and cardiovascular disease and premature mortality

It is estimated that almost 13.000 children in the age of 7 to 17 year old have a reading impairment attributed to exposure to noise from aircrafts. Three quart of them is children in agglomerations.

Based on the reported END data, the exposure to environmental noise contributes to 1,3 million prevalent cases of hypertension among adults. This number increases to 1,5 million prevalent cases when the missing END data is gap filled.

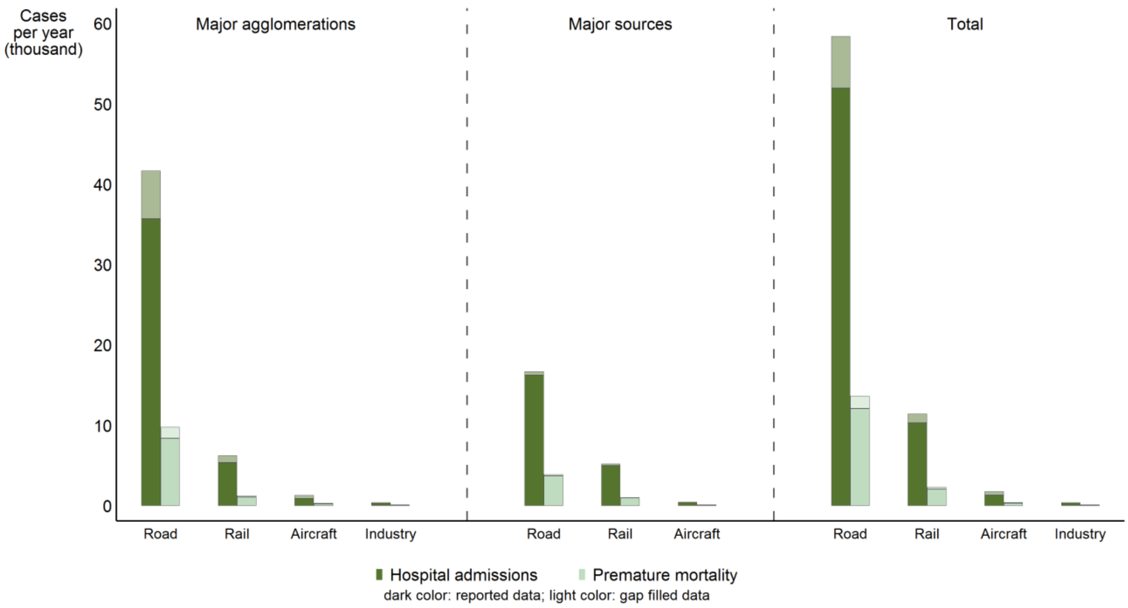
Hypertension increases the risk for coronary heart and cerebrovascular diseases, and also increases the risk for premature mortality due to coronary heart and cerebrovascular disease. The total number of hospital admissions for these diseases related to noise exposure is estimated to be almost 63.000 cases per year, based on the reported data and 72.000 cases per year, based on reported and gap filled END data.

For premature mortality, it is estimated that noise could contribute to 14.500 premature deaths per year, based on the reported data; and 16.600 deaths per year based on reported and gap filled data.

About two third of the burden of disease is related to coronary heart disease and one third to cerebrovascular disease.

In Figure 4.2, the results for hospital admissions and premature mortality based on the reported and gap filled END data are presented according to the noise source and the location of the assessment.

Figure 4.2. Estimated cases per year of hospital admissions and premature mortality due to coronary heart and cerebrovascular diseases, according to the noise source and location of the assessment based on the reported and gap filled END data



About 80% of the disease burden is related to road traffic noise, of which about 70% occurs in the agglomerations.

4.3 Indicative impact of full road traffic noise exposure distribution

Health and well-being effect may also occur at noise levels below 55 dB L_{den} and 50 dB L_{night}, the lowest levels for the noise assessment in the framework of the END (see Annex 1). Also, the noise exposure outside major agglomerations and away from major sources is not part of the END assessments.

Since road traffic noise has the largest contribution to the disease burden, a more comprehensive assessment was carried out for this source to get an indication about how much lower noise levels and exposure in other locations than major agglomerations or near major roads could contribute to the burden of disease related to road traffic noise in Europe.

In Figure 4.3, the indicative results for annoyance for three locations (major agglomerations, major roads and outside agglomerations) are given.

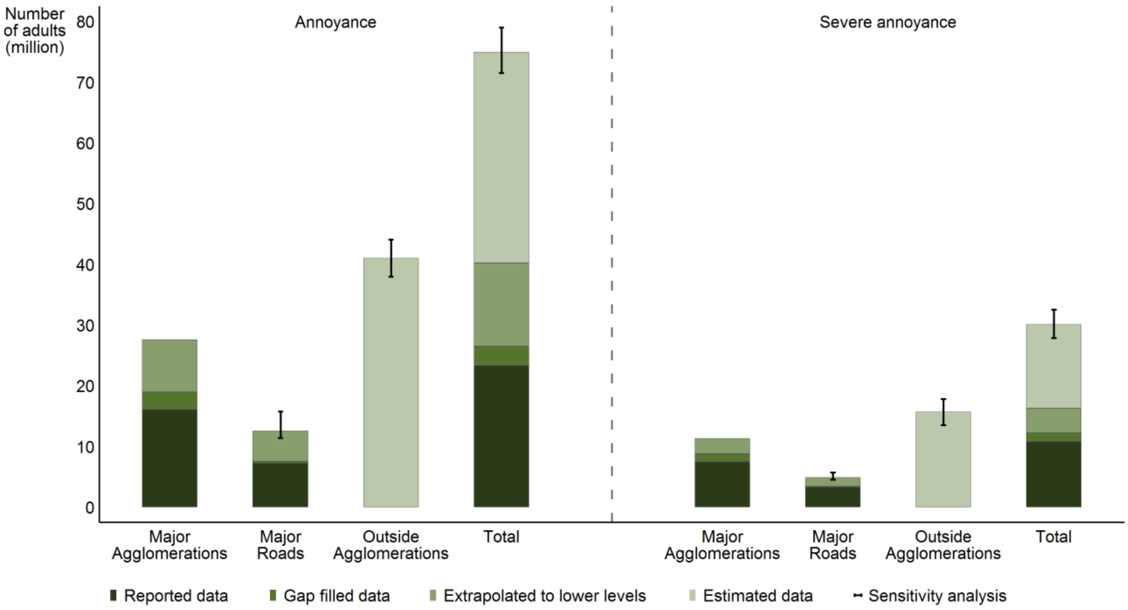
When the END noise distribution of each of the major agglomerations is extrapolated to lower levels to obtain a full noise exposure distribution for the agglomeration, the number of adults with annoyance increases from 19,0 million (based on reported and gap filled data) to about 27,6 million. For severe annoyance, the rise is from 8,8 to 11,3 million adults. When

the END noise distribution of major roads is extrapolated to 45 dB L_{den}, the number of adults considered to be annoyed growths from 7,6 million (based on reported and gap filled data) to about 12,6 million. For severe annoyance, the change is from 3,5 to 4,9 million adults.

The exposure of road traffic noise from roads with an annual traffic below 3 million vehicles (threshold specified by the END) outside agglomerations is estimated to lead to 41 million of adults with annoyance. 15,7 million of them are considered to be severely annoyed by road traffic noise.

The total number of adults with annoyance due to road traffic is, as indication, about 75 million. 30 million of them are considered as severely annoyed. These totals are slightly less than the sum of the three separate locations, since the cumulative exposure of major and minor roads outside agglomerations has been taken into account in the calculation of the total burden.

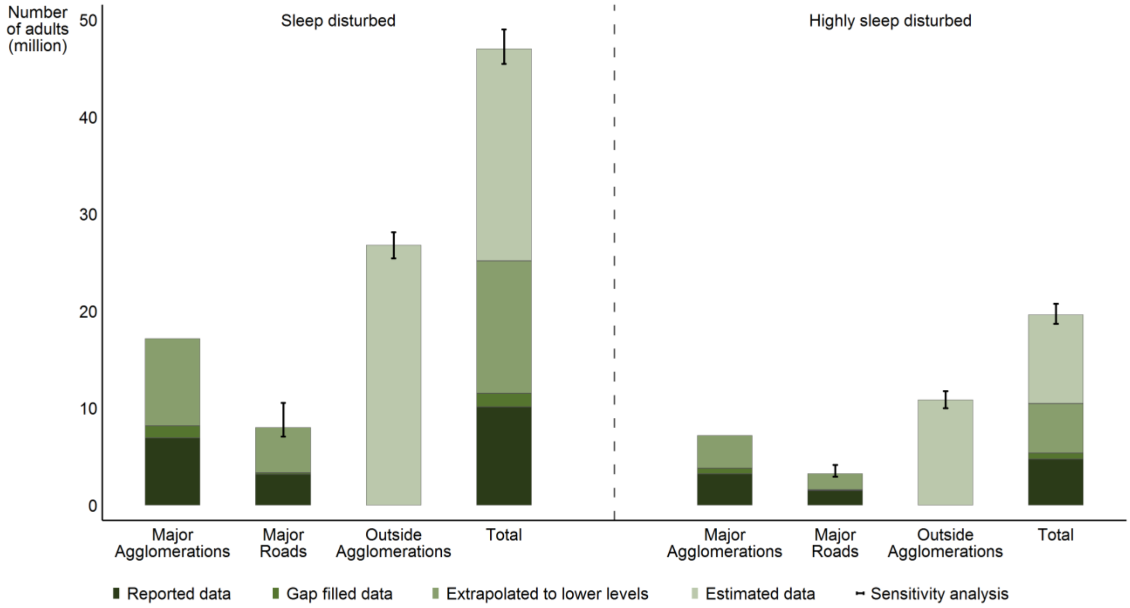
Figure 4.3. Indicative number of adults with (severe) annoyance according to the location of road traffic noise, based on the reported and gap filled END data, data extrapolated to low levels and estimated data for not-END locations



In a similar way, the number of adults that are (highly) sleep disturbed were assessed (Figure 4.4). The estimated total number of adults with sleep disturbed by night-time noise from road traffic is about 47 million. Almost 20 million of them are highly sleep disturbed.

Compared with annoyance (Figure 4.3), the relative contribution of the extrapolation to lower levels in agglomeration or near major roads is larger. The total population size reported in these END assessments for L_{night} is smaller than for L_{den}. The extrapolated noise exposure distribution for L_{night} contains a larger population than the extrapolated L_{den} distribution, since the populations in Figure 4.3 are kept identical for the total L_{den} and L_{night} distribution (the total population for the major agglomerations and within the 45 dB L_{den} 'contour' for major roads).

Figure 4.4. Indicative number of adults that are (highly) sleep disturbed according to the location of road traffic noise, based on the reported and gap filled END data, data extrapolated to low levels and estimated data for not-END locations



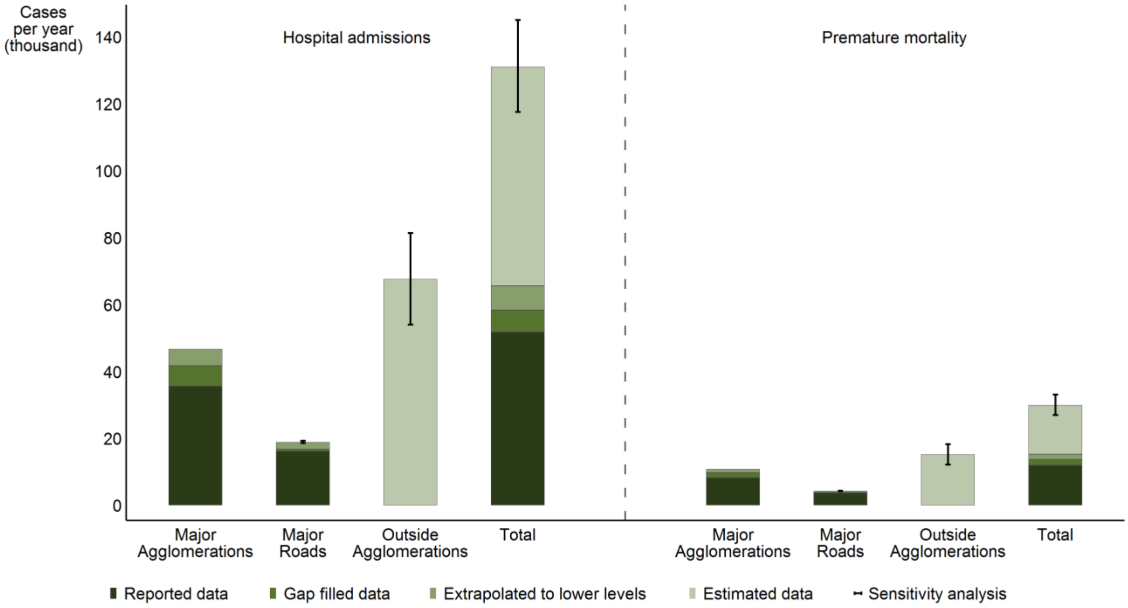
For hypertension related to road traffic noise exposure, the estimated prevalent cases among adults are about 2,6 million when the full distribution is used. The estimation based on the reported and gap filled END road noise data is 1,2 million adults.

The number of prevalent hypertension cases over the various locations has a similar (relative) pattern as shown in Figure 4.5 for the estimated additional cases of hospital admissions and of premature mortality per year related to road traffic noise exposure.

The total estimated additional cases of hospital admissions are 130.000 per year. For premature mortality, this is 30.000 cases per year.

The relative contribution of the extrapolation to lower levels to the total number of cases is much smaller than for annoyance or sleep disturbance, since only the population exposed to noise level above 50 dB L_{den} are assumed to be at risk for noise exposure related coronary heart and cerebrovascular diseases.

Figure 4.5. Indicative cases per year of hospital admissions and premature mortality due to coronary heart and cerebrovascular diseases according to the location of road traffic noise, based on the reported and gap filled END data, data extrapolated to low levels and estimated data for not-END locations



In figures Figure 4.3, Figure 4.4 and Figure 4.5, also the results of a limited sensitive analysis are reported. The extrapolation of noise from major roads to lower levels was established on information from Switzerland and the Netherlands. The estimation of the noise exposure distribution outside agglomerations was based on quantitative relations between population density and the noise distributions, derived from country wide noise maps of Switzerland and the Netherlands. The indicative results in the figures are based on the averaged noise exposure distribution after applying the separate relations from the countries first. The (error) lines in the figures for the impact from noise from major roads, from areas outside the major agglomerations and from the total noise distribution are the results when the information from Switzerland and from the Netherlands is used separately.

For the total number of cases, based on the full exposure distribution, the relative range varies from plus/minus 4% for sleep disturbance up to plus/minus 10% for hypertension, hospital admissions and premature mortality.

4.4 Limitations and perspective

The (main) results, 14,7 million adults that are severely annoyed by noise, 6,1 million adults that are highly sleep disturbed by noise, 72.000 hospital admissions per year and 16.600 cases per year of premature mortality, are the most accurate estimates for the health impact of environmental noise in all END assessment areas.

The results in this chapter are in line with the earlier findings. In the previous report it was indicated that almost 90% of the health impact in the END assessment areas is related to road traffic noise exposure and that about 65% of this occurs in agglomerations. Based on the (additional) reported and gap filled END data, the contribution of the road traffic noise to the

health impact of all noise sources is now estimated on 80-85% of which about 70% occurs in the agglomerations.

Based on expert judgement, it was stated in the previous report that the END assessments may reflect only 20-35% of the total impact of road traffic noise. In this report the total number of adults with annoyance due to road traffic is, as indication, about 75 million while, after gap filling, the END assessments point toward 26,6 million adults (35%). For severe annoyance about 40%, for (highly) sleep disturbed about 26% and for the cardiovascular endpoints about 46% of the total burden is covered by the (gap filled) END assessments for road traffic noise.

Looking into the contributions of the location of the road network, major agglomerations (reported, gap filled and extrapolated to lower levels) contribute about 36% and major roads about 16% to the total burden of disease related to road traffic noise in Europe.

The estimated 30,1 million adults with severe annoyance of road traffic noise is equal to 7,3% of the adult population in the 32 EEA member countries. In some of these countries surveys have been carried out to collect representative information about the percentage of the population severely annoyed by road traffic noise. In the National Noise Attitude Survey 2012 in England, Wales, Scotland and Northern Ireland, 8% of the respondents reported being ‘very’ or ‘extremely’ bothered, annoyed or disturbed by noise from road traffic (Notley et al., 2014). In the German Health Update (GEDA), 5,4% of the responders was very or extremely annoyed by road traffic noise (Niemann et al., 2014). In the SLO-study in the Flemish region of Belgium, this percentage was 8,5% (MAS, 2013) and in a nation-wide Dutch study the percentage was 6% (Van Poll et al., 2011). The four studies have in common that ISO/TS 15666 (2003) was used for the assessment of annoyance. The estimated 7,3% in this chapter fits within the range of the percentage for severe annoyance (5,4-8,5%) assessed with social surveys. This agreement suggests that the derived exposure noise distribution for the whole road network and the subsequent health impact is of sufficient quality to estimate the total burden of (severe) annoyance in Europe.

Sleep disturbance is less often assessed in social surveys than annoyance. Also there is no accepted international standard for the assessment of sleep disturbance, so it is not possible to evaluate the quality of the outcome by comparison with the results of surveys. The estimation of the burden of (highly) sleep disturbed is more uncertain than the burden of annoyance, since the END data contributes with a smaller fraction to the complete road traffic noise exposure distribution and the exposure response relations have been extrapolated over a larger range to lower levels than was the case for annoyance. There is hardly any information available about the possible shape of the relations below 40 dB L_{night} which may lead to an over or underestimation of the burden.

The estimates for hypertension, cardiovascular and cerebrovascular disease and mortality have other uncertainties. First, the estimates do not rely on the complete road traffic noise exposure distribution, but only on the part above 50 dB L_{den}. Small deviations in the exposure distribution around 50 dB may have large consequences for the size of the population at risk and may therefore have a larger impact on the outcome than is the case for annoyance and sleep disturbance. Second, the most comparable data to carry out health impact assessment for cardiovascular and cerebrovascular diseases across European countries are hospital discharge data, since incidence data are mostly unavailable from a central source. Hospital discharge data are an indirect approximation of morbidity. They do not provide a true

measure of incidence, and differences in the baseline rates may also be accounted for by variation between countries in healthcare system organisation as well as rates of abrupt death without hospital admission (Nichols et al., 2013). These uncertainties have unknown consequences for the size of the attributable number of hospital cases. Third, WHO/Europe is carrying out a comprehensive assessment of the health effect of noise that will be published later in 2017. Their assessment may lead to new insights about the location of a possible threshold value for the cardiovascular effects of community noise and about additional health endpoints that could be included in a health impact assessment for noise. It is therefore recommended to update the health impacts assessment after WHO/Europe has published their new community guideline for noise.

It should be emphasized that the result of the health impact for road traffic noise for the whole road network is for more than half based on statistical functions that were transferred from only two countries to the other countries under study. It is difficult to evaluate if this transferability is valid for all countries. The sensitive analysis shows a relative small influence on the outcome of the health impact assessment. But given its limited scope, the validity of the transferability remains unclear. Therefore the results are summed over all countries and results have not presented for individual countries. Also, although the statistical approach provides the insight that more than half of the burden of disease of noise takes place outside END assessment areas, its contribution to the objective of the European Noise Directive to act on a prioritised basis is limited. The statistical approach does not provide insight where the impact precipitates and where hotspots outside END locations occur.

As confirmation of the indicative results as well as to contribute to the objectives of the END, it is advised to consider additional efforts to assess the spatial distribution of noise exposure outside END assessment areas and for lower noise levels. A number of European countries already have nation-wide noise maps based on national noise models, like Switzerland, The Netherlands and Denmark (BAFU, 2009; Schreurs et al., 2010; Høj, J., 2013). Also, it could be explored whether the CNOSSOS road traffic noise prediction model with coarser input data could be used on an European-wide scale as first tier to predict hotspots and/or to assess the spatial distribution of noise exposure outside END assessments areas (see for example Morly et al., 2015). Such an European wide approach had already been carried out for aircraft noise (EASA et al., 2016). 45 European airports were modelled with a multi-airport noise model compliant with the European Directive 2002/49/EC and ECAC Doc. It was estimated that with this approach approximately three quarters of the total population exposed to aircraft noise levels of 55 dB L_{den} and above within EU 28 and EFTA was covered. There are no obvious reasons that prevent to expand the modelling to lower noise levels. This example illustrates that it is likely that, with some additional efforts, also for other noise sources than road traffic, a more complete health impact assessment is feasible.

Box 4.1. Development of new WHO community guidelines for noise

In 1999 and 2009, WHO published reviews dealing with the scientific evidence on noise and health and made recommendations for guidelines to protect human health from environmental noise exposure (Berglund et al, 1999) (WHO, 2009).
Over the years, the number of studies into the effects of noise on health has increased substantially, including several large cohort studies. Earlier studies looked mainly into road traffic and aircraft noise; railway noise or wind turbine noise are addressed in more recent studies. Another development is that several recent studies reported results about new health outcomes in relation to noise such as stroke, diabetes, and obesity.

For these reasons, the WHO regional office for Europe decided to revise their existing health guidelines. The development of community guidelines is protocolled and done in accordance with the "WHO Handbook for Guideline Development" (WHO, 2012). In total, seven reviews are carried out to make a comprehensive and objective assessment of the available evidence from the scientific literature possible. These reviews address (i) annoyance, (ii) sleep, (iii) cognition and mental health, (iv) the unborn child, (v) the cardiovascular and metabolic system, (vi) hearing, and (vii) the effects of interventions. (New) sources-specific exposure-response relations will be derived for a selected number of health outcomes. The results of the evidence reviews are input for the new community guidelines. The evidence reviews and the exposure-response relations will become available soon after WHO has published the new guidelines for community noise. This is expected in the course of 2017.

5 Reducing and managing noise exposure

The END is the main EU legal instrument to identify noise pollution levels and to trigger the necessary action both at Member State and at EU level. One of the underlying principles of the legislation is developing and adopting action plans to reduce environmental noise where necessary and to preserve environmental noise quality where it is good.

Action plans should be of application in the most relevant areas established by strategic noise maps, which are the major transport sources and the largest urban areas in Europe, and should be drawn every 5 years and designed to manage noise issues and its effects including noise reduction if necessary. They should have been drawn up by 18 July 2008 for first round noise mapping assessments and then again by 18 July 2013 for second round noise mapping assessments. The third round of action plans is expected to follow this 5-year cycle and be drawn up by 18 July 2018.

The evaluation and effectiveness of the action plans is expected to be determined by the reduction (or increase) of the population exposure at local scale, especially focusing on the population exposed to the highest noise levels. Nevertheless, and taking into account that some noise abatement measures are implemented based on a long-term perspective, a 5 years cycle is considered not sufficient for measuring and analysing the effectiveness of the action plans (CSES et al., 2015). Provided that the information received concerning action plans account for two reporting years (2009 and 2014), it may have a bit of risk to evaluate its effectiveness, as many of the measures may have not had time to take effect.

While the real benefit of the END will be the prevention of future noise through better land use planning and residential development, the focus is currently on specific interventions for noise reduction that can be quantified. Nonetheless, the cost of implementing a specific measure is not provided when noise action plans are reported, while the cost of the complete action plan is one of the requirements set out in Annex V of the END (although not always reported). The European Commission estimated the social cost for road traffic noise in the EU – including death and disease – at approximately €40 billion per year (European Commission, 2011). The total cost of noise and air pollution in the EU may therefore be approaching €1 trillion (DG ENV, 2016).

Box 5.1. Noise limit values under the frame of the Environmental Noise Directive

The provision of noise limit values under the frame of the Environmental Noise Directive was expected in 2005, in conjunction with the declaration of the first set of noise sources and areas to be studied in the first round of the END.

A distinction was done between noise limit values in force and noise limit values under preparation. Several countries updated the information reported in 2005 while for other countries, the information provided in 2005 is still valid. The information summarized here contains data delivered until 15 of April 2016 by all Member States, and the detailed contents per each member country can be checked in: http://forum.eionet.europa.eu/etc-acm-consortium/library/subvention-2016/task-deliveries-ap2016/task-11111-noise-data-operational-compilation-and-management/b.-final-drafts-approval-eea/subtask-3.-quality-check-reports/quality-check-df3-2016.
There is a high variability of decibel values specified by the Member States concerning limit

values related to L_{den} and L_{night} for the different noise sources (road, rail, aircraft and industrial noise, outside and inside agglomerations). L_{day}, $L_{evening}$, as well as $L_{A,eq}$ indicators are, among others, the most mentioned ones after L_{den} and L_{night} in the documentation delivered. It may happen that national legislation establishes limit values for one or the other indicator, depending if the focus of the legislation is on strategic noise mapping, on noise inside buildings or on noise from machinery.

It is important to highlight that the majority of countries refer to different land uses when defining the noise limit values of application. Depending on the dedicated or established use of a specific area, a different degree of protection would be needed against harmful noise. Therefore, it is considered important to determine acoustic zones in the territory (inside and also outside cities) in order to legislate and establish adequate noise limit values.

Some examples about this zoning, from more to less protection against environmental noise, are:

- Areas that require an increase protection against noise; i.e. natural areas devoted to tourism and recreation, the immediate environs of hospitals, health resorts and rest homes, and areas in natural parks.
- Areas where interventions causing environmental noise should not be permitted; i.e. residential areas, the environs of childcare, education and primary healthcare facilities, playing fields, public parks, public areas of greenery and public recreation grounds.
- Areas where interventions causing less disturbing noises are permitted; i.e. retail, business and residential areas designed for both residential purposes and small business or similar manufacturing activities (mixed areas), agricultural areas, public centres where administrative, retail, services and catering, and entertainment take place.
- Areas where interventions that cause more disturbing noise are permitted; i.e. non-residential areas designed for heavy or light industry or similar manufacturing processes, transport, warehousing or service activities, and noisy communal activities.

5.1 Noise abatement measures

The decision about which noise abatement measures are implemented in the noise action plans are at the discretion of the competent authorities, but should notably address priorities which may be identified by the exceedance of any relevant limit value of by other criteria chosen by the Member States.

There are essentially two routes to abate noise. Firstly, noise emissions can be reduced at source, through measures relating to vehicles/drivelines, tyres, road surfaces and traffic management. Secondly, noise can be abated by reducing the exposure of people by means of anti-propagation or insulation measures (by increasing the distance between source and receiver, for example, or hampering noise propagation by insulating buildings or constructing noise barriers). Measures at source level are often considered the most cost-effective (Milford et al., 2013).

Nevertheless, a greater collection of noise abatement measures per noise source can be found in the action plans developed by the competent authorities, which have been summarized and categorized in Table 5.1. Examples per noise source have also been provided, considering that in case of agglomerations, every measure (and category) could be applicable.

Table 5.1. Compilation of noise abatement measures into 7 main categories analysed in the noise action plans (2014)

Measures	Roads	Railways	Airports
Source orientated measures	Cleaner vehicles technologies (hybrid electric buses, hydrogen fuel cell powered vehicles for captive fleets and passenger cars, low emission passenger cars); Noise emission regulations; Low noise tyres design for (low noise) vehicles (including heavy vehicles); Noise reducing devices (NRD) in general: improve the knowledge of its acoustic performances; Noise reducing devices (NRD): assess its sustainability	Common rolling stock certification standard; Retrofitting of existing freight trains / Measures on freight trains; Braking system; Optimised wheels' / wheel absorbers; Grinding of rails; Noise reducing devices (NRD) in general: improve the knowledge of its acoustic performances; Noise reducing devices (NRD): assess its sustainability; Renewal of public transport fleet / low-noise trams.	Measures referred solely to the airplane
Measures at the receiver	Sound insulation / indoor noise score rating models / sound-proof windows; Orientation of rooms according to their sensitivity; Shielding through building parts; Noise score rating models for the outdoors; Sound absorbing façades / high low frequency absorption at façades if building; Building design and structure.		Extra insulation measures (on the roof)
Traffic management	By-pass roads / Traffic re-routing / park and ride scheme; Replacement of road surfaces to low noise road surfaces; Pedestrian crossings; Speed limits & traffic calming; Improve traffic flow = reduce traffic volumes; Street design / street network / roundabouts; Truck restrictions.	Measures regarding changes of operating conditions.	Operational measures: Preferred routes/selected runways; Noise Abatement; Procedures: Night time flight bans.
Measures on the propagation path	Screens / sound barriers / noise barriers optimization; Dams; Cuttings; Embankments; Tunnels; High low frequency isolation in the propagation pad; New designed vegetated low barriers (or low barriers using natural materials, stones or soil); Buildings as noise barriers"	Barriers / new designs; Bogie shrouds; Low screens; Railway and tram depots; Tram track improvements / low noise tracks (for trams).	
Socio-economic measures	Optimisation of the modal split (increase the share of public transport)/ environmentally friendly transport modes; Reduction of freight transport / new concepts for distribution of goods; Congestion charging scheme; Car sharing; Increase the occupancy / workloads of the vehicles; Subsidies/prices strategies (e.g. parking) to favour cleaner vehicles; Managing mobility demand / intelligent traffic management; Low-noise night time delivery.	Optimisation of the modal split (increase the share of public transport)	Financial programmes specific for the airports/aircrafts: money to insulate the houses inside a specific contour/ penalty for the aircraft companies
Land use and urban planning	Traffic bans (zones) / access control measures / car free (residential) areas /Q-Zones: zones in inner city	Planning of the railways/tram network; Land use planning; Parks embedded in Q-Zones /design of	No houses around the airport/No permission to build an airport next to houses

	where only quiet low emission vehicles are tolerated; Avoidance of motorised traffic; Land use planning; Parks embedded in Q-Zones /design of parks and green spaces; Identification of hot spots on noise maps with a computerized method; Calming green waves; Noise zoning / distance from road or railway line to the residential buildings; Indicate quiet spaces to be protected.	parks and green spaces; Identification of hot spots on noise maps with a computerized method; Calming green waves; Noise zoning / distance from railway line to the residential buildings; Indicate quiet spaces to be protected.	
Promotion and awareness	Increase public awareness; Avoid the generation of additional traffic; Promote public transport & also encourage cycling and walking; Driving behaviour	Increase public awareness; Avoid the generation of additional traffic.	Increase public awareness; Avoid the generation of additional traffic.

For the evaluation of the noise action plans related to all noise sources specified in the END (delivery from 2014), the information related to the noise abatement measures have been studied and categorized as shown in Table 5.1. The analysis has been performed separately by noise source and for those action plans being provided following the specifications on how to submit noise action plans' information to the EC and the EEA. It is not the intention to develop a thorough analysis of the contents of the action plans but to explore which are the measures typically applied and for which source, if any.

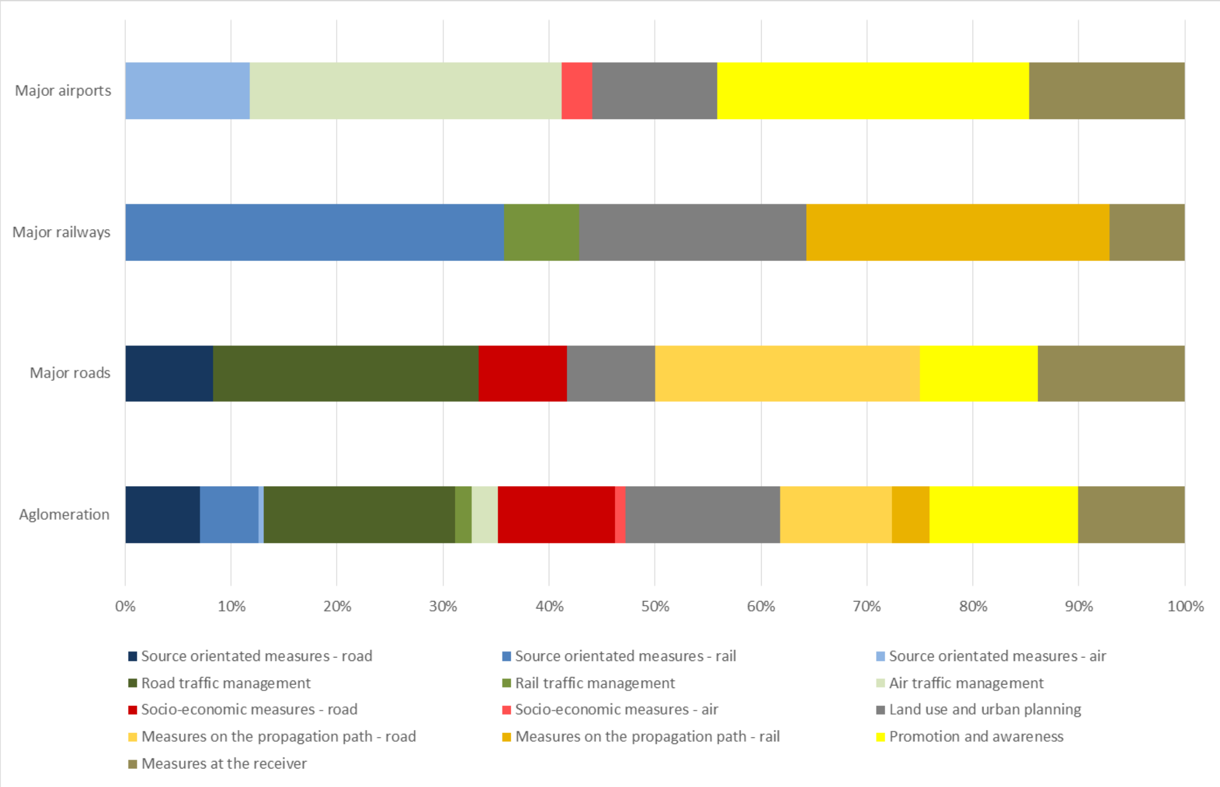
For agglomerations, measures targeting road traffic management (e.g., replacement and improvement of road surfaces, improve traffic flow and introduction of lower speed limits) are the most predominant (18%), followed by measures related to land use and urban planning (15%) and measures promoting the use of more environmentally friendly transport modes, increasing awareness and avoiding the generation of additional traffic (14%). Measures targeting directly the vehicles, this is the source, are the less predominant (7%), and they usually refer to the incorporation of cleaner technologies in bus fleets (in Figure 5.1).

The measures for major roads mainly address road traffic managements (25%) with traffic re-routing and introduction of stricter speed limits as examples of these measures, and measures on the propagation path (25%) with the introduction of noise barriers as the most frequent example of this type of measures.

Major railways differ from major roads, and source orientated measures (36%) followed by measures on the propagation path (29%) are the most predominant. Land use and urban planning is present in high percentage (21%), and example is the design of urban landscape to ensure that noise insensitive buildings are used as barriers to protect sensitive structures.

In the case of major airports, air traffic management measures as for example night time flight bans are the most predominant (29%) together with promotion and awareness measures (29%) usually in the line of sharing information with the affected communities. Measures at the receiver (15%), as for instance the installation of sound-proof windows and sound insulation, are also an important part of the total measures for major airports. Measures oriented towards land use and urban planning (12%) usually represent noise zoning and mapping of the protected areas to ensure that noise levels do not increase and the maintenance, if not reduction, of the people exposed to airport noise.

Figure 5.1. Analysis of END noise action plan measures (2014)



It is clear that noise abatement measures should prioritise the most at-risk groups through targeted interventions to improve living conditions and pollution levels for these people. Spatial planning to identify priority areas, building design and protection and enhancement of quiet areas may also play a role (Harris and Pinoncély, 2014; Pope et al., 2014). Urban sprawl and inadequate spatial planning have created situations in many cities where it is more convenient for people to drive than to use more sustainable forms of transport, so actions to tackle congestion and promote sustainable and active forms of transport (including cycling and walking) can have joint benefits for all sectors of society by helping to reduce noise pollution and their impacts on physical and mental health.

But, given the factors that determine environmental noise in cities and also outside urban areas, one single measure alone is often not enough. It is important to develop the noise action plans looking at synergies and benefits that could be obtained by integrating noise management with other areas, such as air quality, transport and mobility and urban development and housing.

Box 5.2. How cities are working with noise pollution?

The Working Group Noise[3] EUROCITIES[4] launched a survey among its members in order to evaluate the status of noise pollution in the cities.

Fourteen stakeholders answered the questions posted, including cities as Paris region, The Hague, Helsinki, Antwerp, Genova, Rotterdam, Stockholm and Brighton & Hove.

One of the highlights was that noise pollution is not amongst the highest priorities at political level (scoring a bit more of 3 out of 10 points). Nevertheless, 40% of the responding cities declared that the municipality has a specific budget related to noise pollution measures, but this budget can vary a lot year by year and it is highly depending on the upcoming plans at city level: from hundred - thousand Euros until several million Euros, if multi-annual plans are considered.

At the question of which are the measures that the cities mostly work with, in the majority of cases the measures highlighted were related to road traffic management (indicating the use of quiet road surfaces and speed limits as the main measures used), followed by measures on the propagation path mainly related to noise screens. Also mentioned were the measures at the receiver (including protective actions such as better windows, acoustic insulation of buildings or even reallocation of buildings) and the measures related to urban and land use planning. Promotion and awareness measures were mentioned only by one of the cities consulted.

Nevertheless, when the cities were asked about the most efficient measures to abate noise in the city, the majority mentioned land use and urban planning for noise prevention and because the effects are more in a long term perspective. But for a noisy situation that is already in place, both road traffic management measures (mentioning all the cities quiet road surfaces) as well as measures at the receiver (façade insulation, building renovation including acoustic and thermal insulation) are the ones considered most efficient. Measures at the propagation path and its maintenance were mentioned only by few cities, while no one considered promotion and awareness or socio-economic measures among the most efficient

[3]The Working Group Noise EUROCITIES was launched in 2006 with the aim to:

- exchange knowledge and experience on noise, noise effects and noise abatement
- influence the European policies where and when needed
- especially support municipalities with the implementation of the Environmental Noise Directive 2002/49/EC
- to gain awareness among politicians, policy makers and the public
- to initiate, support and participate in European projects under the LIFE, INTERREG and FP7 programmes

More Information can be found in: https://workinggroupnoise.com

[4]EUROCITIES (http://www.eurocities.eu/) is the network of major European cities. It was founded in 1986 by the mayors of six large cities: Barcelona, Birmingham, Frankfurt, Lyon, Milan and Rotterdam. EUROCITIES objective is to reinforce the important role that local governments should play in a multilevel governance structure. The aim to shape the opinions of Brussels stakeholders and ultimately shift the focus of EU legislation in a way which allows city governments to tackle strategic challenges at local level.

ones.

Finally, the questionnaire ends up asking about how the cities communicate the noise pollution situation to the citizens, with the following outcomes to be highlighted:

- Around 70% of the cities have an up-to-date digital noise pollution map pointing out the decibel level
- Only 30% of the cities use a real time measurement as a complement to the noise pollution map they are developing
- Nearly 40% of the respondent cities have made an end user survey about their experience concerning noise pollution, obtaining interesting results from the citizens perspective, such as:
    - People is becoming much more sensitive to noise pollution and annoyance for road traffic noise is increasing
    - Nevertheless, sensitivity to leisure noise in city centre and especially in areas with high concentration of leisure activities is increasing, as well as noise produced by waste collection and city cleaning activities
    - Quietness was not the most prominent aspect for people using green areas to compensate for environmental noise and other stressful conditions in urban areas, but on the other hand, it has been suggested to use sound as a resource in public realm planning.

Box 5.3. European Green Capital Award

The European Green Capital Award is an award for a European city based on its environmental record. The award was launched on 22 May 2008 and the first award was given to Stockholm for the year 2010. The European Commission has long recognised the important role that local authorities play in improving the environment, and their high level of commitment to genuine progress. The European Green Capital Award has been conceived as an initiative to promote and reward these efforts. Noise is one of the environmental aspects that is evaluated.

In 2011 Hamburg was rewarded with the EGCA. Among the overall environmental performance it was also recognised the integrated approach to noise abatement. by looking for synergies with other areas like transport, climate or urban development. This ensured a more efficient use of resources and a positive feedback between different environmental sectors.

Being a large industrial city, Hamburg has been exposed to noise from different sources, in particular from road traffic. The problem was so acute on the seventies that the Hamburg's Senate passed noise protection regulation and created an own department to enforce these laws. However, road traffic remained a problem given the multiple factors involved in the regulation. Moreover, many of the available spaces in the inner city to overcome housing shortage are exposed to high levels of noise pollution.

In 2008, a "Noise Action Plan" with noise maps was drawn up for the whole city. This plan shows noise pollution levels along roads, at the airport and along rail routes, and recommends measures for bringing about a reduction in these levels. This led to a comprehensive urban development concept for a sustainable reduction in noise pollution. During the second stage

of the process, which has taken place over the past two years, the focus has been on individual boroughs, where residents have been asked to identify hotspots where noise pollution is a particular problem. Public participation was welcomed. From as early as June 2009, the State Ministry of Urban Development and the Environment established "Noise Forums." These forums represent a platform for those who are interested in and for those who are affected by noise pollution. Here they can report local problems and present their ideas for mitigating noise.

As a rule, individual measures are insufficient to achieve effective noise reduction on roads with heavy traffic. Concepts are therefore required that are composed of various measures and utilize different potentials. These include planning -, traffic- and design -related measures as well as technical, constructional and organizational measures. Application of precautionary measures at the source of noise is of primary importance. Possible options for the reduction of road traffic noise are delineated in a three -stage process in the Strategic Noise Action Plan:

1. Development and description of possible noise reduction measures.
2. Comparison of these noise reduction options with existing plans as well as assessment of relevance and efficacy.
3. Conclusions concerning fields of action in which synergies are possible, or where action is required or conflicting objectives exist.

In addition, Hamburg aims to tackle the existing serious housing shortage through inner development. However, many of the eligible spaces within the city are exposed to high levels of noise pollution. Planes, cars, trains, industry, trade, sports events and recreation are all sources of noise that can have a major negative impact on health. For this reason, "Hamburg Noise Guidelines in Urban Land Use Planning 2010" were developed, and in these, the various types of noise are described. Innovative solutions for resolving noise-related conflicts are proposed in order to ensure long-term, healthy housing conditions even in locations vulnerable to high levels of noise pollution.

The main element of "Hamburg Noise Guidelines in Urban Land Use Planning 2010" is the development of the "HafenCity solution". Instead of providing protection against noise by using soundproof windows that have to be kept closed, this solution seeks to achieve sound protection using special window designs that can deliver low noise levels indoors even when windows are partially open. Once noise maps had been created, a two-phase Strategic Noise Action Plan was drawn up for the whole of Hamburg, after which the individual boroughs of Hamburg were investigated. What is special about this approach is that citizens were also called upon to actively participate in Noise Forums by reporting irritating sources of noise in their environment and putting forward proposals for improvements to eliminate the problem.

The second phase of the Noise Action Plan involves finding concrete solutions to noise problems by reviewing findings from previous years and assessing all proposals submitted by citizens for their technical feasibility. Furthermore, a minimum of two traffic routes or areas particularly susceptible to noise pollution are to be selected from each borough, which will be put forward for inclusion in a potential "Noise Abatement Emergency Programme".

6 Conclusions

Four years after the closure of the official reporting date for strategic noise maps concerning the whole coverage of the Environmental Noise Directive, data is still incomplete. Nevertheless, with current data available, noise still is one of the most pervasive pollutants in Europe and drivers such as economic growth, expanding urbanisation, more extensive transport networks and increased industrial output will present challenges to protecting the quality of the European soundscape.

It is clear from END data that noise from road traffic is the most dominant source of transport noise, both due to its geographical extent and by the numbers of people it affects. Railway noise does not have the same high numbers of exposure that road traffic reaches, but the numbers of people affected remain significant. In addition, while airports do not affect a wide geographical area, the effects of aircraft noise are clearly differentiated from the other noise sources being evaluated. In cities, it would appear from END data reports that sea ports and industrial sites are not affecting a very great number — around 600.000 people reported (estimated up to 1 million people), compared to the other sources — yet citizen ratings of noise in Europe indicate that industrial noise is the second most dominant source affecting our environment.

The greatest challenge to assessing Europe's noise environment lies mainly with the still missing data and therefore, the gap filling exercise undertaken combined with the extrapolation to lower noise levels and to the complete European territory, going beyond the scope of the END.

The impacts on human health of environmental noise pollution shows that there are at least 16.600 cases of premature death per year in Europe, 72.000 cases of hospitalisation every year, almost 15 million adults are severely annoyed by noise and 6 million adults who suffer sleep disturbance. By enlarging the assessment to noise levels below 55 dB L_{den} and 50 dB L_{night} and to other locations than major agglomerations or near major roads, the extent of the the burden of disease related to environmental noise in Europe increases. Focusing on road traffic noise, since it is the source with the largest contribution to the disease burden, the total number of adults with annoyance due to road traffic would be about 75 million, 30 of them considered severely annoyed.

Challenges related to the END, both for strategic noise mapping and action planning, should take into consideration coping with the lack of human and financial resources, the lack of adequate data, the complex competencies arrangements and coordination among different institutions, etc. although assessing the economic impacts of inaction against noise pollution should also be taken into account.

The evaluation of the END (Evaluation of regulatory fitness: REFIT process[5]) will provide the basis for discussion and further development of noise policy in Europe, with the view to strengthen the strategy to protect our health and preserve Europe's natural soundscape by

[5] http://ec.europa.eu/environment/noise/evaluation_en.htm

learning more about the sources of noise affections people living. In this process, it is also very important to establish synergies with other pollutants in order to achieve a more integrated solution that would ensure a better health and well-being of urban populations.

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Annex 1 Relationship between noise exposure and health and well-being effects

In Table A, an overview is given of characteristics of the exposure-response relations that were applied in the current assessment. These relations describe the association between several noise sources (road traffic, rail traffic, aircraft and industry) and health- and wellbeing effects, and were based on pooled analyses of individual data or meta-analyses (combining the results of different studies). The relations in Table A were used for the health impact assessment.

Table A. Core characteristics of the applied exposure-response relations

Health and well-being effect	Population	Applied from†	Noise source and 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); industry: Miedema and Vos, 2004
(Severe) sleep disturbance	Adults	45 dB L_{night} and < 30 dB L_{night}	Road traffic, railways and industry: Miedema & Vos (2007); aircraft: Janssen & Vos (2009)
Reading impairment	7 to 17 years old	50 dB L_{den}	Only aircraft: adapted from Clarck et al., 2006
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)
Cerebrovascular disease (mortality & morbidity)	Total population	50 dB L_{den}	All sources: ad-hoc meta-analysis based on 6 studies (Houthuijs et al., 2014)

For annoyance and sleep disturbance a starting point 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 starting point values 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 addition to the health impact assessment with reported and gap filled END data, END road noise data was extrapolated to lower levels, so the application of a threshold value for annoyance and for sleep disturbance may have consequences. For annoyance and sleep disturbance from road traffic noise the (original) functions can also predict the probability at levels below the threshold values (see Miedema and Oudshoorn, 200; Miedema and Vos,

2007). The probability for being annoyed by road traffic noise with data reported is about 4% at 42 dB and about 2% at 37 dB, and for severe annoyance about 1% at 42 dB L_{den}. At 40 dB L_{night}, the predicted percentage of sleep disturbed is almost 7%, and highly sleep disturbed about 2%. Given these percentages, it is likely that below the common applied threshold values for annoyance and sleep disturbance, a distinct part of the population might be at risk. For this reason, the exposure response functions to lower levels of exposure have also been extrapolated.

Vienneau et al (2015) found indications for a linear exposure–response association between the incidence of coronary heart disease and transportation noise starting as low as 50 dB. Van Kempen and Babisch (2012) based their exposure-response relation between road traffic noise and the prevalence of hypertension on a meta-analysis of 24 studies with an exposure range of 45-75 dB $L_{Aeq,16hr}$. The exposure range in the meta-analysis of Babisch and Van Kamp for the relation between aircraft noise and the prevalence of hypertension was 50 to 70 dB L_{den}. Based on this information a starting point of 50 dB L_{den} was assumed for the relation between transportation noise and hypertension, coronary heart disease and cerebrovascular disease.

Crude country-specific incidence data on hospital discharges and mortality from the European Cardiovascular Disease Statistics (Nichols et al., 2012; Nichols et al., 2013) were used to assess the ‘base-line’ risks for coronary heart disease and stroke. Age and sex specific prevalence estimates for three different regions in Europe (Kearney et al, 2005) were applied to assess the ‘base-line’ prevalence of hypertension.