Environmental noise in Europe — 2020

ISSN 1977-8449

25
1994-2019
European Environment Agency

EEA Report | No 22/2019

Environmental noise in Europe — 2020

25 1994-2019
European Environment Agency

Cover design: EEA
Cover photo: © Gaia Russo
Layout: Rosendahls a/s

Luxembourg: Publications Office of the European Union, 2020

ISBN 978-92-9480-209-5
ISSN 1977-8449
doi:10.2800/686249

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Tel.: +45 33 36 71 00
Internet: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

Contents

Acknowledgements

Lead author

Eulalia Peris (EEA)

Contributors

Núria Blanes (Universitat Autònoma de Barcelona), Jaume Fons (Universitat Autònoma de Barcelona), Miquel Sainz de la Maza (Universitat Autònoma de Barcelona), Maira José Ramos (Universitat Autònoma de Barcelona), Francisco Domingues (Universitat Autònoma de Barcelona), Katarzyna Biala (EEA), Monika Peterlin (EEA), Catherine Ganzleben (EEA) and Martin Adams (EEA).

The EEA acknowledges comments received on the draft report from the European Environment Information and Observation Network national reference centres, the European Commission and the World Health Organization. These comments have been included in the final version of the report as far as possible.

Executive summary

Chronic exposure to environmental noise has significant impacts on physical and mental health and well-being. Exposure to environmental noise is a widespread problem in Europe, with at least one in five people exposed to levels considered harmful to health. Given the negative impacts on human health and the large number of people affected, environmental noise is therefore a significant concern for citizens and policy makers. Reducing environmental noise is a key objective under the Seventh Environment Action Programme (7th EAP) and the Environmental Noise Directive (END).

This report presents an updated assessment of the population exposed to high levels of environmental noise and the associated health impacts in Europe, based on the new World Health Organization (WHO) *Environmental noise guidelines for the European region* (2018). It builds on previous assessments undertaken by the EEA, *Noise in Europe* (2014) and *Quiet areas in Europe — The environment unaffected by noise pollution (*2016). The report also documents actions being taken to manage and reduce noise exposure and reviews the progress made towards meeting the obligations established in the END and the 2020 noise objectives outlined in the 7th EAP. The evaluation of the status of exposure to environmental noise in Europe is based on the latest data collected under the END. The report also describes other relevant issues, such as inequalities in exposure to environmental noise as well as impacts on biodiversity.

Key findings

Environmental noise, and in particular road traffic noise, remains a major environmental problem affecting the health and well-being of millions of people in Europe. More specifically:

Environmental noise from road, rail, aircraft and industry sources affects millions of people, causing significant public health impacts

- Long-term exposure to environmental noise is estimated to cause 12 000 premature deaths and contribute to 48 000 new cases of ischaemic heart disease per year in the European territory. It is estimated that 22 million people suffer chronic high annoyance and 6.5 million people suffer chronic high sleep disturbance. As a result of aircraft noise, 12 500 schoolchildren are estimated to suffer learning impairment in school.
- These significant health impacts are most likely to be underestimated, with new WHO evidence demonstrating effects at levels below the obligatory END reporting thresholds. In addition, the END does not comprehensively cover all urban areas, roads, railways and airports across Europe.
- Exposure to environmental noise does not affect everyone equally. Socially deprived groups, as well as groups with increased susceptibility to noise, may suffer more pronounced health-related impacts of noise.

Policy objectives on environmental noise have not yet been achieved

- The number of people exposed to high levels of noise has not decreased, and millions of people remain exposed to noise levels harmful to health. Therefore, the 7th EAP objective of significantly reducing noise pollution in the EU and moving closer to the WHO recommended levels by 2020 has not been achieved.
- Although some progress has been made on the reporting of noise mapping by countries, more

than 30 % of data required is still not available after the 2017 END legal reporting deadline. In terms of reporting action plans, significant delays and poor quality suggest that countries may not have taken the necessary steps to address noise pollution. To protect the health of the European population, better implementation of the END is needed.

The number of people exposed to high levels of road traffic noise remains high and is likely to increase in the future

- Environmental noise, and in particular road traffic noise, is a major environmental problem in Europe. At least 20 % of the EU population live in areas where traffic noise levels are harmful to health. As mentioned above, exposure is likely to be underestimated.

- More specifically, an estimated 113 million people are affected by long-term day-evening-night traffic noise levels of at least 55 dB(A). In addition, 22 million are exposed to high levels of railway noise, 4 million to high levels of aircraft noise and less than 1 million to high levels of noise caused by industries.

- The number of people exposed to high levels of noise has broadly remained stable since 2012. However, the population exposed to environmental noise is projected to increase because of future urban growth and an increased demand for mobility.

Countries are undertaking a variety of actions to reduce and manage environmental noise, but as yet it is difficult to evaluate their benefits in terms of positive health outcomes

- In urban areas, more than 50 % of measures to reduce and manage noise focus on mitigating noise at source. Measures at source are extensively used to reduce and manage noise in areas outside cities that are affected by major railways (52 %), major airports (70 %) and major roads (39 %). Managing and reducing noise through land use and urban planning represents a very small percentage of the measures chosen to address noise.

- Measures to target air pollution in European cities often offer co-benefits in terms of reducing environmental noise. However, not all interventions are equally effective for both stressors. Nevertheless, cost-benefit estimations for mitigation measures can be more favourable if the positive impacts of addressing both air quality and noise are taken into account. This calls for effective coordination between communities of policymakers and stakeholders working to address noise and air pollution.

More progress is needed on the designation and protection of 'quiet areas' in cities, countries and regions

- A significant number of countries, cities and regions have definitions of quiet areas in place as well as selection criteria for designating them. However, to date, the designation and protection of quiet areas have mainly taken place in cities, and more progress is needed in designating and protecting quiet areas in the open country.

- The availability and accessibility of quiet areas in cities, including residential and green areas, is highly dependent on transport infrastructure, in particular on how the location of roads and airports affects the structure of the urban environment. The presence of quiet areas within a city does not guarantee that the population has access to those areas, which suggests that the designation of quiet areas in cities requires accessibility aspects to be taken into account.

Noise pollution is a threat to terrestrial and marine wildlife

- Anthropogenic noise affects a wide variety of terrestrial and marine wildlife species causing a range of physiological and behavioural responses. These can reduce reproductive success and increase mortality and emigration, resulting in lower population densities.

- At least 19 % of nature protection areas covered under Natura 2000 are located in areas where noise levels are above the END reporting thresholds because of road, railway and aircraft traffic.

1 Introduction

1.1 Background

Environmental noise is a pervasive pollutant that adversely affects the health and well-being of European citizens and wildlife. Although noise is a product of many human activities, the most widespread sources of environmental noise are those related to transport (Box 1.1). As a result, noise caused by transport is considered the second most significant environmental cause of ill health in western Europe, behind fine particulate matter pollution (WHO and JRC, 2011; Hänninen et al., 2014). According to the World Health Organization (WHO), prolonged exposure to environmental noise is associated with an increased risk of negative physiological and psychological health outcomes (WHO, 2018). These include cardiovascular and metabolic effects, cognitive impairment in children, as well as severe annoyance and sleep disturbance. With projections of rapid urban growth and an increased demand for transport, a simultaneous increase in noise exposure and the associated adverse effects can be anticipated (Jarosińska et al., 2018). Furthermore, there is also increasing evidence regarding the harmful effects of transport noise on wildlife (Shannon et al., 2016). The effects of noise vary depending on the species, although, generally, noise can interfere with feeding, hunting and the breeding behaviour of the animals.

In 2014, the EEA produced its first report on environmental noise in Europe, based on data reported by countries under the Environmental Noise Directive (END) (EU, 2002). The report concluded that noise at that time was indeed a major environmental health problem in Europe, with clear negative health impacts, although a reliable assessment was not possible because of the significant delay in the implementation of the END and shortcomings in the information reported by countries (EEA, 2014b).

In the years since the publication of the EEA's first report on noise, significant developments have taken place with respect to legislation and approach. For instance, the EU has recently developed a common method for noise mapping which will harmonise future noise-mapping assessments, making it easier to compare data across countries (EC, 2019) (Box 1.2). In terms of legislation, there have been advances in the retrofitting of a significant part of the rail freight fleet with quiet brake blocks and in ensuring that airports take more effective action on noise-operating restrictions (EU, 2014; ERA, 2018). Apart from EU legislation, there have also been some societal changes, which may lead to reduced noise, such as an increase in the use of electric vehicles (EEA, 2018a). At the same time, with the publication in 2018 of the new WHO environmental noise guidelines (WHO, 2018), there is greater insight into the effects of noise on the exposed population and a growing awareness of the need to reduce noise below the END thresholds where feasible. Driven by the publication of these new guidelines, the EU has recently adopted a harmonized approach to calculating the health effects of noise by updating Annex III of the END.

The aforementioned developments in the areas of health and legislation implementation, as well as the availability of new data on noise submitted by countries under the END reporting obligations, means that it is timely to perform an updated assessment of environmental noise exposure to understand the health impacts in Europe (Box 1.3). Furthermore, this report serves to track the progress made towards

Box 1.1 Environmental noise

There are variations in how environmental noise is defined. For instance, the WHO describes environmental noise generically as that emitted by all sources, except sources of occupational noise exposure in workplaces (WHO, 2018). The END is more specific in its definition, considering environmental noise as unwanted or harmful outdoor sound created by human activity, such as noise emitted by different means of transport — road traffic, rail traffic, air traffic — and industrial activity. In this report, unless stated otherwise, we refer to environmental noise as that defined under the END. Therefore, noise in workplaces, noise from domestic activities, noise from neighbours or recreational venues, noise from wind turbines, or noise caused by military activities is not considered in this report.

Box 1.2 Common noise assessment methods for Europe (CNOSSOS-EU)

Since 2008, the European Commission and the Joint Research Centre, along with a large number of noise experts across Europe, have been developing a common assessment method for noise mapping known as CNOSSOS-EU. Following an update of Annex II of the Environmental Noise Directive published in 2015, all EU Member States as of 1 January 2019 are required to use this method when preparing noise maps in accordance with the END. As a result, it is expected that future noise mapping assessments will be better harmonised, making it easier to compare data across countries.

In the current noise mapping data, there are inconsistencies, as Member States were allowed to use their own national methods. For instance, different methods use different input assumptions and parameters related to certain meteorological conditions or absorption characteristics of the ground, which can lead to differences of up to 5-10 dB between calculations. Other inconsistencies arise because of differences in the ways that noise levels and the population are assigned to buildings. It is expected that, with the new method, the variation resulting from the input parameters of the emission part will have less than a 2-dB effect on the calculated results.

However, the CNOSSOS calculation method originally presented in 2015 still has room for further improvement. A working group consisting of representatives from various Member States has recently prepared a proposal for the improvement of the calculation method itself (Kok and van Beek, 2019). The group also highlighted the need to create a guidance document with details on specific calculation issues, to achieve comparable results between countries.

Box 1.3 New in the *Environmental noise in Europe — 2020* report

The *Environmental noise in Europe* report presents a regular assessment of Europe's environmental noise and the associated impacts on health and the environment. Based on the latest official data available from countries, this updated 2020 report presents new information, including:

- the current noise situation based on the latest data submitted under the END;
- an overview of the observed trends 2012-2017;
- an estimation of future noise projections;
- an estimation of health effects, using new information introduced by the WHO *Environmental noise guidelines for the European region*;
- an overview on inequalities and vulnerability to noise exposure;
- an overview of the effects of noise on wildlife;
- an assessment of the availability and accessibility of areas potentially unaffected by noise in cities;
- an assessment of current noise management and mitigation practices, based on the latest data submitted under the END.

meeting the 2020 noise objectives outlined in the Seventh Environment Action Programme (7th EAP) (EU, 2013) and can inform the development of future environmental action programmes.

1.2 The environmental noise policy context in Europe

The EU's 7th EAP recognises that a large number of people living in major urban areas are exposed to levels of noise at which adverse health effects frequently occur (EU, 2013). To address this environmental stressor, the 7th EAP establishes the objective that, by 2020, noise pollution in the EU needs to be significantly decreased, moving closer to the WHO recommended levels. To meet this objective, the 7th EAP identified the need to implement an updated EU noise policy aligned with the latest scientific evidence, as well as measures to reduce noise at source, including improvements in city design.

In Europe, the END provides the primary legislative framework for achieving noise reduction. The directive offers a common approach to avoiding and preventing exposure to environmental noise through the reporting of noise mapping and action planning, thereby reducing its harmful effects and preserving quiet areas (EU, 2002). It is important to note that the directive does not set limit values but reporting thresholds. In particular, the END requires Member States to:

- Produce strategic noise maps on a 5-year basis for all major roads, railways, airports and urban agglomerations, using harmonised noise indicators. These are roads with more than 3 million vehicle passages per year, railways with more than 30 000 train passages per year, airports with more than 50 000 movements per year and urban areas with more than 100 000 inhabitants.

- Determine the number of people exposed to each of the above noise sources, inside and outside urban areas, as well as large industrial installations inside urban areas using 5 dB interval bands at L_{den} ≥ 55 dB and at L_{night} ≥ 50 dB (Box 1.4).

- Adopt action plans based on noise mapping results, with a view to preventing and reducing environmental noise, in particular in areas where exposure levels can induce harmful effects on human health.

- Select and preserve areas of good acoustic environmental quality, referred to as 'quiet areas', to protect the European soundscape.

Accompanying the END, there are a number of specific legislative measures that aim to address or control noise at the source such as by imposing noise limits on certain vehicles or equipment, including their constituting components, or by restricting their operation (Annex 1). Examples of recent developments related to the regulation of noise at source since the last reporting obligations for noise mapping in 2012 are:

- the noise technical specifications for interoperability relating to rolling stock noise — Regulation 1304/2014 — which set out noise limits for new rail vehicles, in addition to renewed or upgraded wagons, as well as the subsequent amendment of the same regulation of 16 May 2019, which requires operators to retrofit most of the existing wagons with quiet brakes before the end of 2024 (EU, 2019a);

- Regulation (EU) No 598/2014 on the procedures concerning the introduction of noise-related operating restrictions, which ensure that airports apply evidence-driven and proportional noise-operating restrictions in accordance with the internationally agreed 'balanced approach';

- Regulation (EU) No 540/2014 on the sound level of motor vehicles and of replacement silencing systems as well as subsequent amendments regarding the acoustic vehicle alerting system requirements for electric and hybrid vehicles.

An overview of the EU policy framework is shown in Figure 1.1 In addition to the EU policy on noise, many countries have put in place national limit values (Box 1.5).

An important new document linking environmental noise and its effects on human health is the WHO *Environmental noise guidelines* for the European region (WHO, 2018), which contains an updated set of recommended outdoor exposure levels of environmental noise over those previously published in the *Guidelines for community noise* and the Night noise guidelines for Europe (Berglund et al., 1999; WHO Europe, 2009). The document presents specific recommendations on guideline exposure levels and interventions to reduce exposure to road, railway, aircraft, wind turbine and leisure noise sources. The guidelines indicate that health and well-being can be

Box 1.4 Noise indicators and definitions used

L_{den} (day-evening-night noise level): the long-term average indicator designed to assess annoyance and defined by the Environmental Noise Directive (END). It refers to an A-weighted average sound pressure level over all days, evenings and nights in a year, with an evening weighting of 5 dB and a night weighting of 10 dB.

L_{night} (night noise level): the long-term average indicator defined by the END and designed to assess sleep disturbance. It refers to an A-weighted annual average night period of exposure.

High noise levels: defined in the Seventh Environment Action Programme as noise levels above 55 dB L_{den} and 50 dB L_{night}.

Round/phase of noise mapping: used to define the 5-year cycle periods for which the reporting obligations of noise mapping need to be fulfilled under the END. There were noise mapping obligations in 2007, 2012 and 2017, which represent the situation in the preceding calendar year.

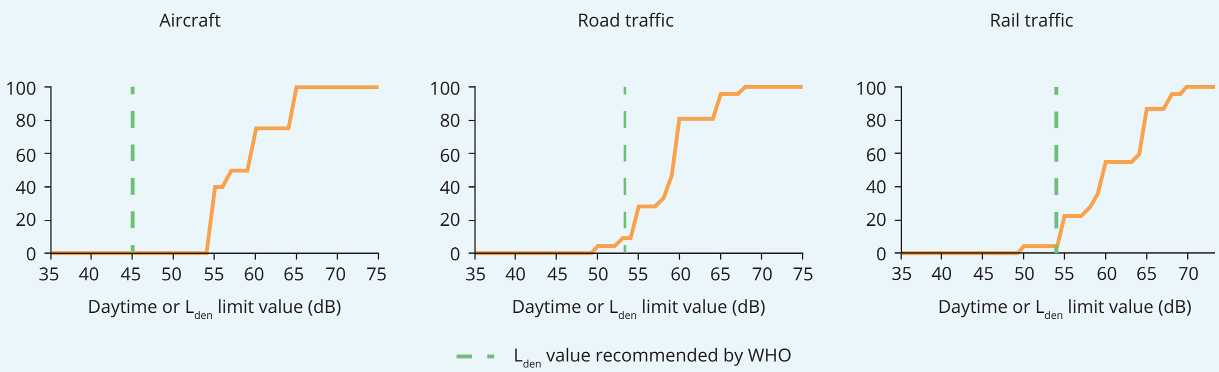
Box 1.5 National noise limits in the European region

Many countries across Europe have put in place national limit values for environmental noise that have, in part, emerged from studies on noise and health relationships and various policy making processes. When defining these national limit values, countries take into consideration different aspects including the type of the noise source, the time of day during which the noise occurs, whether the noise is due to an existing or new development, the land area type and the sensitivity of the receivers.

Current national limits mainly focus on transport sources, such as road, railway and aircraft, as well as on industry sources, although some countries also specify limits for wind turbines. Conversely, a small number of countries focus instead on non-source-specific limits. National noise legislation is often based on daytime (L_{day}) and night-time (L_{night}) limit values, whereas the END sets reporting thresholds using the day-evening-night (L_{den}) and night-time (L_{night}) indicators. In addition to this, the values of the noise limits still vary widely across countries, and in many cases national limit values are different from the threshold values used to develop action plans under the END.

The national limit values do not reflect the recently published WHO environmental noise guidelines (WHO, 2018). On the one hand, the majority of countries have limit values that are considerably higher than the noise levels recommended by the WHO. On the other hand, the limit values do not reflect the fact that people are generally more annoyed and sleep disturbed by aircraft noise than by road or rail noise at the same decibel level. For instance, a large number of countries allow equivalent or higher levels of aircraft noise than of road noise, and a smaller percentage of countries apply higher rail noise limits than those for road noise (see figure below).

Percentage of countries with a limit value lower than or equal to x-axis value



The actual consequences of exceeding the limits also vary between countries and sources. For traffic noise, active and passive noise measures commonly need to be considered to reduce noise levels above the limit. For industrial sources and wind turbines, exceedance often leads to a prohibition of further activities. Fines for the operators or financial compensation of residents also occur and may indirectly stimulate noise reduction measures.

Source: Peeters and Nusselder (2019) — work carried out within the Interest Group on Noise Abatement (IGNA) of the European Network of the Heads of the Environmental Protection Agencies.

affected at levels below the END reporting thresholds (i.e. $L_{den} \geq 55$ dB and $L_{night} \geq 50$ dB) (Chapter 3). At the moment, there is a lack of data on the number of people exposed below these thresholds, as reporting at such levels remains voluntary for countries.

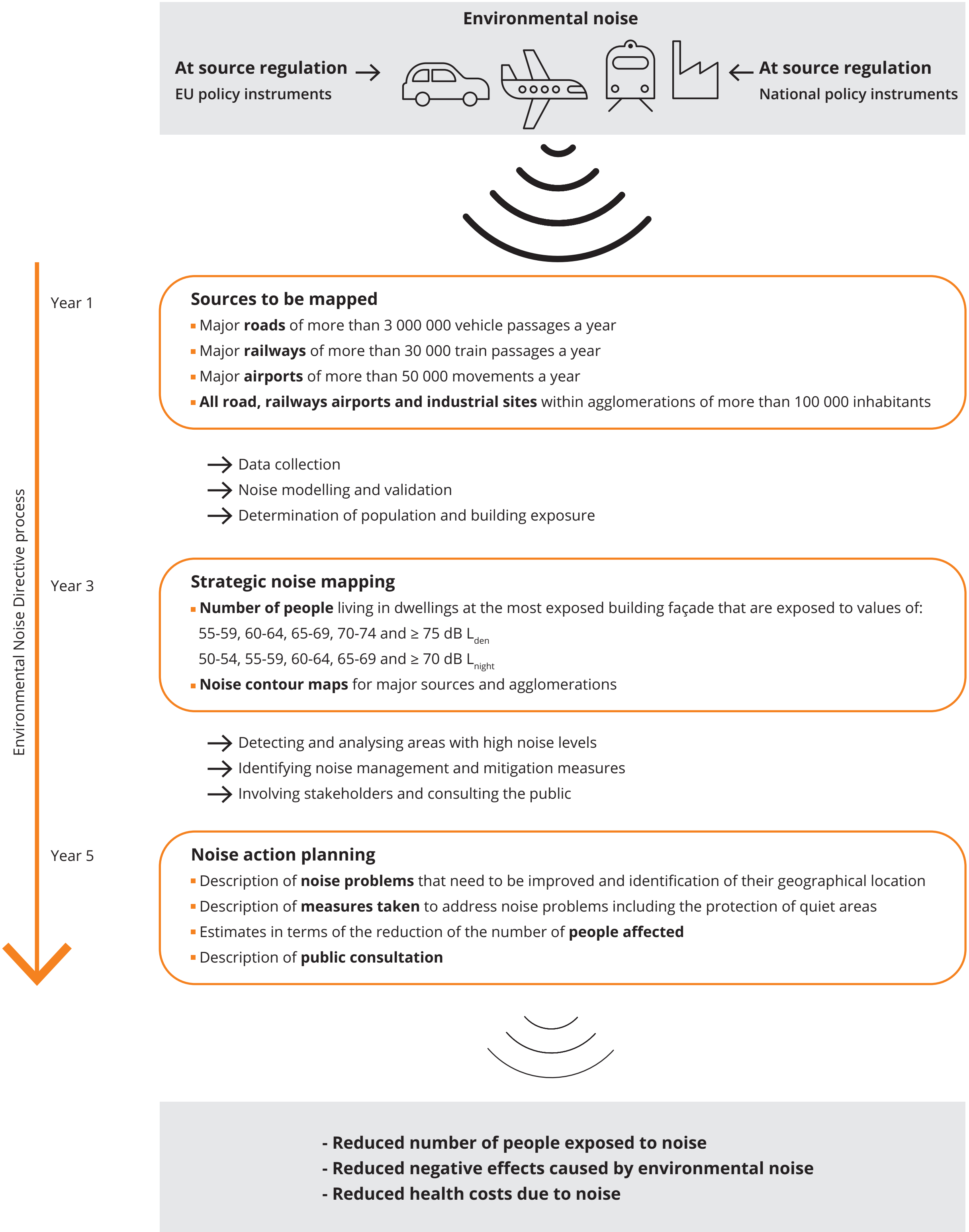
1.3 Scope

The report mainly focuses on the 2017 reporting of noise mapping and presents an updated overview and analysis of the noise situation in Europe as well as impacts on health and the environment. The report is structured as follows:

- Chapter 2 reviews the progress made towards meeting current policy targets and objectives established in the END and the 7th EAP. The chapter presents the current noise situation, based on the latest data submitted under the END. In addition, an overview of the observed trends 2012-2017 as well as an estimation of future noise projections are presented.

- Chapter 3 assesses the negative impacts of exposure to environmental noise on health and well-being. This chapter focuses on assessing health effects using the new information introduced by

Figure 1.1 Overview of the EU policy framework on environmental noise reduction



Source: EEA, based on EU (2002).

the WHO *Environmental Noise Guidelines* for the European Region (WHO, 2018).

- Chapter 4 consolidates available evidence on inequalities and vulnerability to noise exposure.

- Chapter 5 explores the evidence of the impacts of noise on terrestrial and marine wildlife. The chapter presents a synthesis of the physiological and behavioural responses in wildlife.

- Chapter 6 assesses the availability and accessibility of areas potentially unaffected by noise, referred to as 'quiet areas', in European cities. This also includes information on how countries, cities and regions designate and protect quiet areas within their territories.

- Chapter 7 shows measures being undertaken by countries to mitigate noise exposure. The chapter summarises current noise management and mitigation practices employed for roads, railways, airports and agglomerations based on the END reporting. This also includes an assessment of the possible noise co-benefits of the air pollution mitigation measures that are currently used.

1.4 Data used in this report

This report presents a comprehensive overview and analysis of environmental noise in Europe and is focused on the data officially reported by the 33 EEA member countries (EEA-33), excluding Turkey, in accordance with the END. Under the terms of the END, the third round of noise mapping was to be finalised by countries by 31 December 2017, and the action planning process was to be finalised by 18 January 2019. Because some countries were still in the process of providing the required data at the time of writing, gap-filling was performed to complete any missing information to ensure a full assessment of environmental noise in Europe (ETC/ATNI, 2019b).

The data used cover noise sources, such as roads with more than 3 000 000 vehicle passages a year, railways with more than 30 000 train passages per year and airports with more than 50 000 movements per year, as well as all roads, railways, airports and industries in urban areas of more than 100 000 inhabitants. Overall, the END 2017 covers all road, rail, air and industrial noise sources for 511 urban areas across the European territory, 420 791 km of major roads, 49 729 km of major railways and 89 major airports.

The results presented in this report mainly focus on the number of people exposed to noise levels of 55 dB or higher during the day-evening-night period as well as night-time noise levels of 50 dB or higher. Throughout the report, and according to the 7th EAP, these levels are also referred to as 'high noise levels'.

Table 1.1 Gives an overview of the data included in each chapter.

Finally, it should be noted that, for the data presented in this report, countries have used a wide variety of calculation methods and approaches in developing a noise map (Table 1.2 and Box 1.6). Therefore, the results of the different countries or years generated by different prediction methods may not be fully comparable and should be interpreted with caution. Throughout the report, there are charts with individual country and city information. However, rather than comparing population exposure data across countries, the information presented in the subsequent chapters is aimed at illustrating the possible causes of the variability encountered.

Table 1.1 Overview of the data included in each chapter

	Data cut-off point	END dataset	Type of data	Reporting year	Type of assessment
Chapter 2	1 January 2019	Population exposed to noise	Gap-filled	2012 2017	Quantitative analysis
Chapter 3	1 January 2019	Population exposed to noise	Gap-filled	2017	Quantitative analysis
Chapter 4	1 January 2019	Population exposed to noise	Gap-filled	2017	Literature review and quantitative analysis
Chapter 5	—	—	—	—	Literature review
Chapter 6	1 January 2019	Noise contour maps	Reported	2017	Qualitative and quantitative analysis
Chapter 7	1 April 2019	Action plans	Reported	2019	Qualitative and quantitative analysis

Table 1.2 Examples of different noise calculation methods reported across the EEA-33 for the 2017 phase of noise mapping

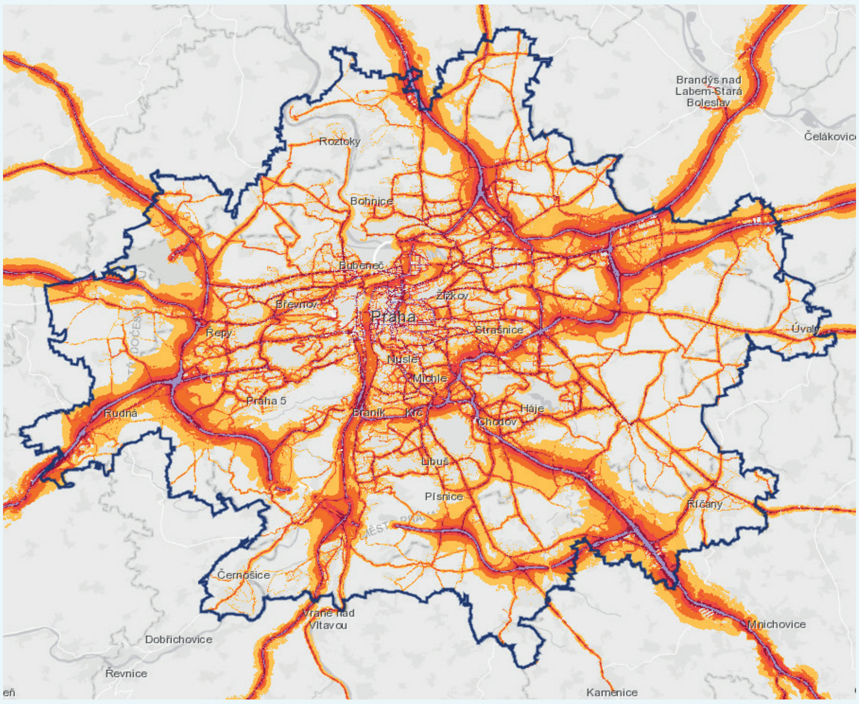
Road	RVS 4.02; NMPB-Routes-96: NMPB-Routes-2008; RMW 2002 (SRM II); CNOSSOS-EU 2015; sonROAD; VBUS; Nord2000; CRTN; RTN 1996; SKM2
Rail	RMR 2002 (SRM II); CNOSSOS-EU 2015; VBUSch; Nord2000; NMT 1996; ONR 30511; NMPB-Routes-2008; SKM2
Air	ÖAL 24; FLULA; INM; DANSIM; ECAC Doc 29; Nord2000; VBUF
Industry	ISO 9613-2; VBUI; Danish EPA 5/1993; CNOSSOS-EU; Nord 1996 and Nord2000; HRMI

Box 1.6 Dissemination of noise maps — the EEA Noise Observation and Information Service for Europe (NOISE)

The Environmental Noise Directive requires strategic noise maps to be made available to the public and disseminated in accordance with Directive 2003/04/EC on public access to environmental information. Environmental noise maps are used for quantifying and visualising noise pollution levels geographically. Environmental noise varies across geographical space, depending on the location of the noise source, the receiver and the intervening obstacles, including terrain, buildings and barriers (Murphy and King, 2014). Therefore, the process of noise mapping helps relevant stakeholders in identifying locations that are subject to excessive noise levels and are home to individuals residing in those areas (Murphy and King, 2014).

There are different approaches on how to build a strategic noise map depending on the source and the coverage to be mapped. Typically, the approaches used combine predictive techniques and measurements. Noise maps are usually built using commercial software programs that have embedded algorithms for national noise sources and propagation characteristics (Murphy and King, 2014). After calculations have been undertaken using the commercial software, it is best practice to validate modelling results using measurements to ensure that the model provides an accurate representation of the true sound environment (Murphy and King, 2014). However, there are other situations in which strategic noise maps are developed primarily with the data measured (Manvell et al., 2004).

At present, countries mainly disseminate the strategic noise maps by making this information available online. Some countries go even further and present noise mapping information in the form of interactive maps to the public through their website for national data — e.g. Defra (2019). Data collected from the 2017 noise mapping phase is made publicly available through the EEA's NOISE website and provides available information on noise contour maps submitted under the END as well as information on the amount of the population exposed to high levels of noise at country level and at city level. An example of what can be found in the EEA noise viewer is shown below.



Praha

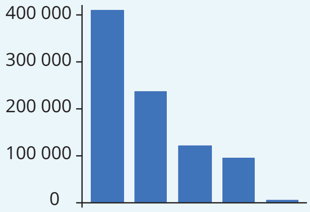
In Praha, a total of **876 300** people are exposed to day-evening-night average sound levels of **55 dB** or higher from **road** traffic.

Number of people exposed to high levels of **road** traffic noise in Czechia (**L_{den} ≥ 55 dB**)

Czechia	**2 493 400**
Inside urban areas	1 767 700
Outside urban areas	725 700

Noise bands for Roads-L_{den}

Total number of people exposed per each noise band for **Roads-L_{den}**



Source: http://noise.eea.europa.eu

2 Population exposure to environmental noise in Europe

Key messages

- Environmental noise, and in particular road traffic noise, is a major environmental problem in Europe. At least 20 % of the EU population lives in areas where traffic noise levels are harmful to health.
- Road traffic noise is the most dominant source of environmental noise. An estimated 113 million people are affected by long-term day-evening-night traffic noise levels of at least 55 dB(A). In addition, 22 million are exposed to high levels of railway noise, 4 million to high levels of aircraft noise and less than 1 million to high levels of noise caused by industries. These values are likely to be underestimated, given that the END does not comprehensively cover all urban areas, roads, railways and airports across Europe.
- The number of people exposed to high levels of noise since 2012 has broadly remained stable. However, an increase in the population exposed to environmental noise is projected as a result of future urban growth and increased mobility demand.
- The Seventh Environmental Action Programme objective of significantly reducing noise pollution in the EU, moving closer to the World Health Organization's recommended levels by 2020, will not be achieved.
- More than 30 % of the noise mapping data required are still not available after the 2017 legal reporting deadline. Gap-filling was used to present a complete picture.

2.1 Overall European picture in 2017

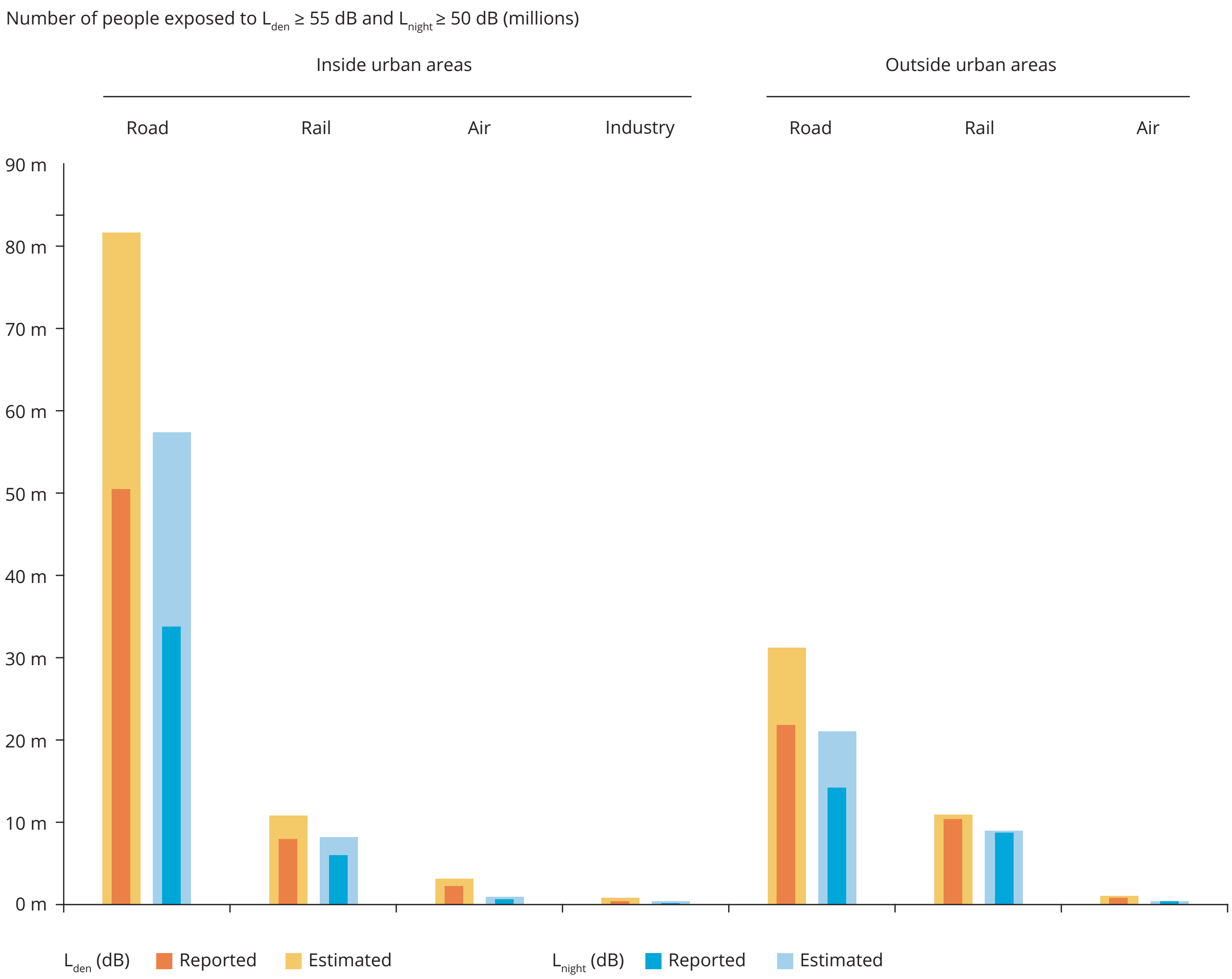
Table 2.1 and Figure 2.1 show the latest estimations of population exposure for the most recent round of noise mapping within and outside urban areas for the 33 EEA member countries (EEA-33), excluding Turkey (Box 2.1). The overall number of people exposed to day-evening-night noise levels of 55 dB or higher is estimated to be 113 million for road traffic noise, 22 million for railway noise, 4 million for aircraft noise and less than 1 million for noise caused by industries. Similarly, road traffic is by far the biggest source of environmental noise during the night-time, followed by railway, air and industrial noise. Considering road traffic noise only, these results indicate that at least 20 % of Europeans are exposed to high levels of noise during the day-evening-night period and more than 15 % during the night-time period, from which adverse health effects can occur. These values are likely to be underestimated, given that the Environmental Noise Directive (END) does not comprehensively cover all urban areas or all roads across Europe (Figure 2.2). Furthermore, there is also a considerable number of people exposed to rail, aircraft and industry noise. However, it is difficult to estimate the total number of citizens exposed to high levels of noise across all sources, as certain individuals may be exposed to a combination of noise sources, and thus a simple summation would lead to double counting.

Table 2.1 Population exposure to environmental noise, based on areas covered by strategic noise maps in 2017, EEA-33 (Turkey not included)

		Number of people exposed to L_{den} ≥ 55 dB (million)		Number of people exposed to L_{night} ≥ 50 dB (million)	
		Reported	Estimated	Reported	Estimated
Inside urban areas	Road	50.6	81.7	33.8	57.5
	Rail	7.9	10.7	6.0	8.1
	Air	2.2	3.1	0.6	0.9
	Industry	0.3	0.8	0.2	0.4
Outside urban areas	Road	21.8	31.1	14.2	21.1
	Rail	10.4	10.9	8.7	9.0
	Air	0.8	1.1	0.4	0.4

Notes: Based on data submitted up until 1 January 2019 for the 2017 END submission of strategic noise mapping. Reported data refer to data submitted by countries and estimated data refer to data gap-filled because of incomplete reporting.

Figure 2.1 Population exposure to environmental noise based on areas covered by strategic noise maps in 2017, EEA-33 (Turkey not included)



Sources: EEA (2019c, 2019d).

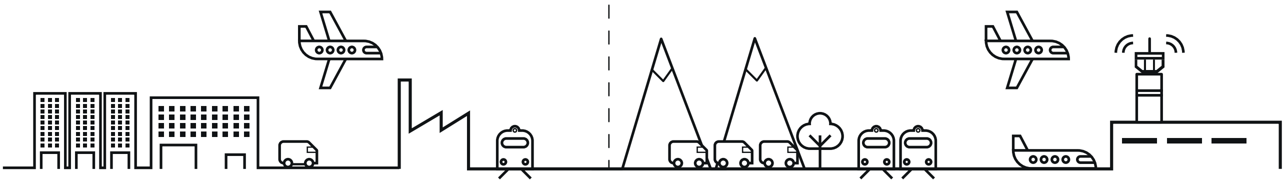
Figure 2.2 Coverage under the Environmental Noise Directive

INSIDE URBAN AREA

Roads, **railways**, **airports** and **industries** inside urbanised areas — called agglomerations — with a population exceeding 100 000 inhabitants and a population density such that the Member State considers it to be an urbanised area.

OUTSIDE URBAN AREA

Major roads > 3 000 000 passages/year
Major railways > 30 000 passages/year
Major airports > 50 000 movements/year



Notes: Coverage since 31 December 2008.

Source: EEA, based on EU (2002).

Box 2.1 Completeness of the data reported under the Environment Noise Directive (END) — for strategic noise maps in 2017

Despite the progress made on reporting noise data since the END was introduced in 2002, significant work remains until the implementation is complete. The table below shows the completeness of the data that have been reported under the END 2017. The data set is approximately 66 % complete, and the missing data had to be estimated based on previous reporting years, leading to uncertainties in the assessment. The reporting of the major sources of noise outside agglomerations was much more complete than for urban areas of more than 100 000 inhabitants. Roads (59-62 %) and industrial sources (43-52 %) inside urban areas are the least complete data sets, while the railway data set is the most complete (73 %). Similarly, major roads outside urban areas make up the least complete data set (67-70 %) and major railways outside urban areas make up the most complete (96 %). Detailed information on data completeness by country can be found in Annex 2.

Apart from the completeness of the data set, there may be other uncertainties due to the lack of consistency in calculation, mapping method and approaches for estimating exposure between countries. In 2017, a common method for noise mapping was not available, making the situation across Europe difficult to assess. Despite these inconsistencies and uncertainties, the data in this assessment serve as the best available information on population exposure to environmental noise in the EU.

Estimated completeness of the information reported under the END 2017 in terms of population exposure to noise, EEA-33 (Turkey not included)

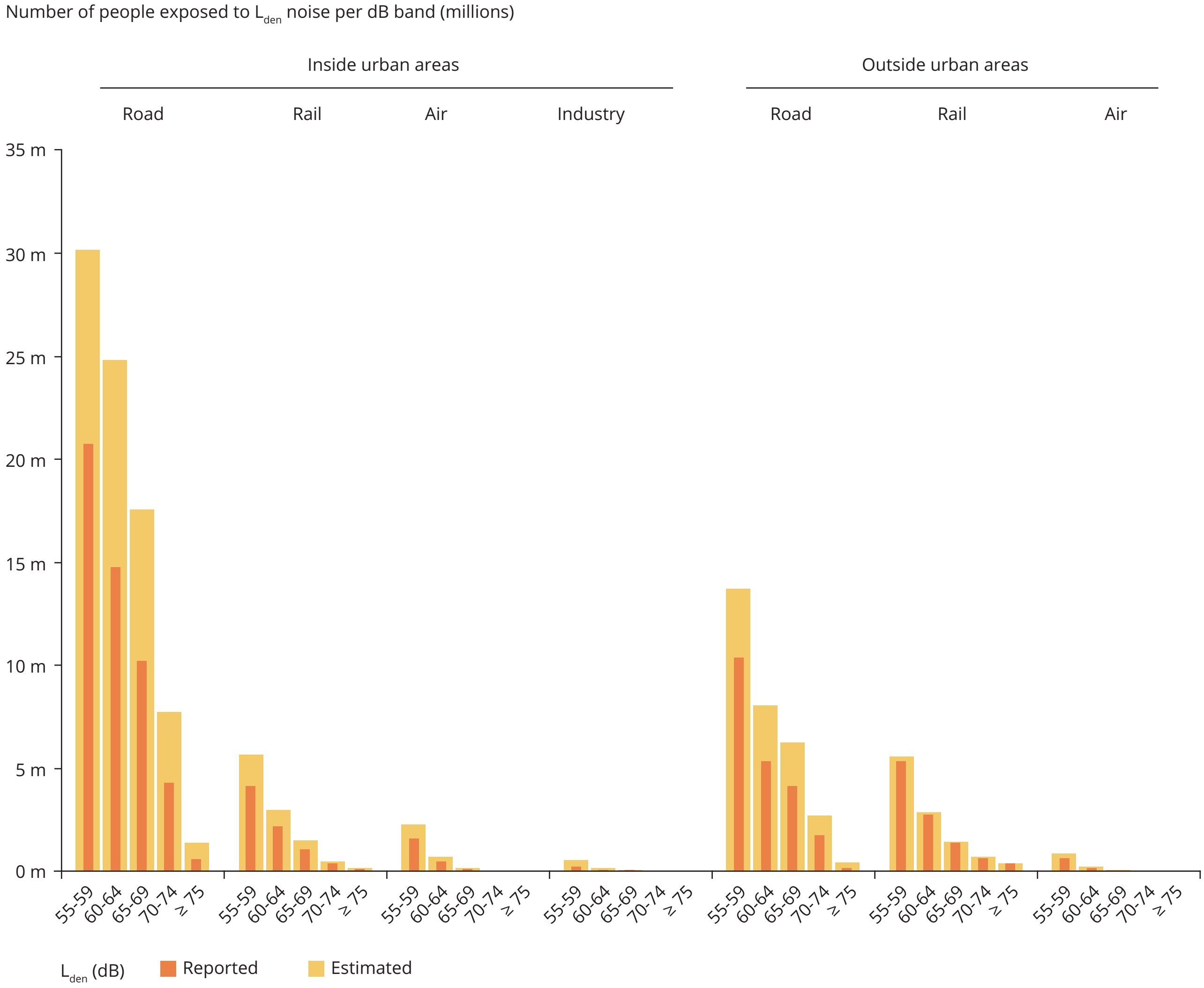
Source	**Completeness of submitted data in %**							
	Inside urban areas				Outside urban areas			Total
	Road	Rail	Air	Industry	Road	Rail	Air	All
$L_{den} \geq 55$ dB	61.9	73.3	70.7	42.7	69.9	96.0	76.1	67.4
$L_{night} \geq 50$ dB	58.8	73.4	71.4	52.1	67.1	96.4	82.3	65.5

Note: The completeness was calculated using the reported number of people exposed to noise levels above the END thresholds and the expected number of people exposed above these thresholds, as calculated within the gap-filling exercise (ETC/ATNI, 2019b).

The END requires the provision of exposure data in 5 dB bands for L_{den} and L_{night} above the reporting thresholds. Health risks can increase with higher levels of exposure, and noise abatement measures to be implemented may also differ, depending on the source and the specific noise-level band being addressed.

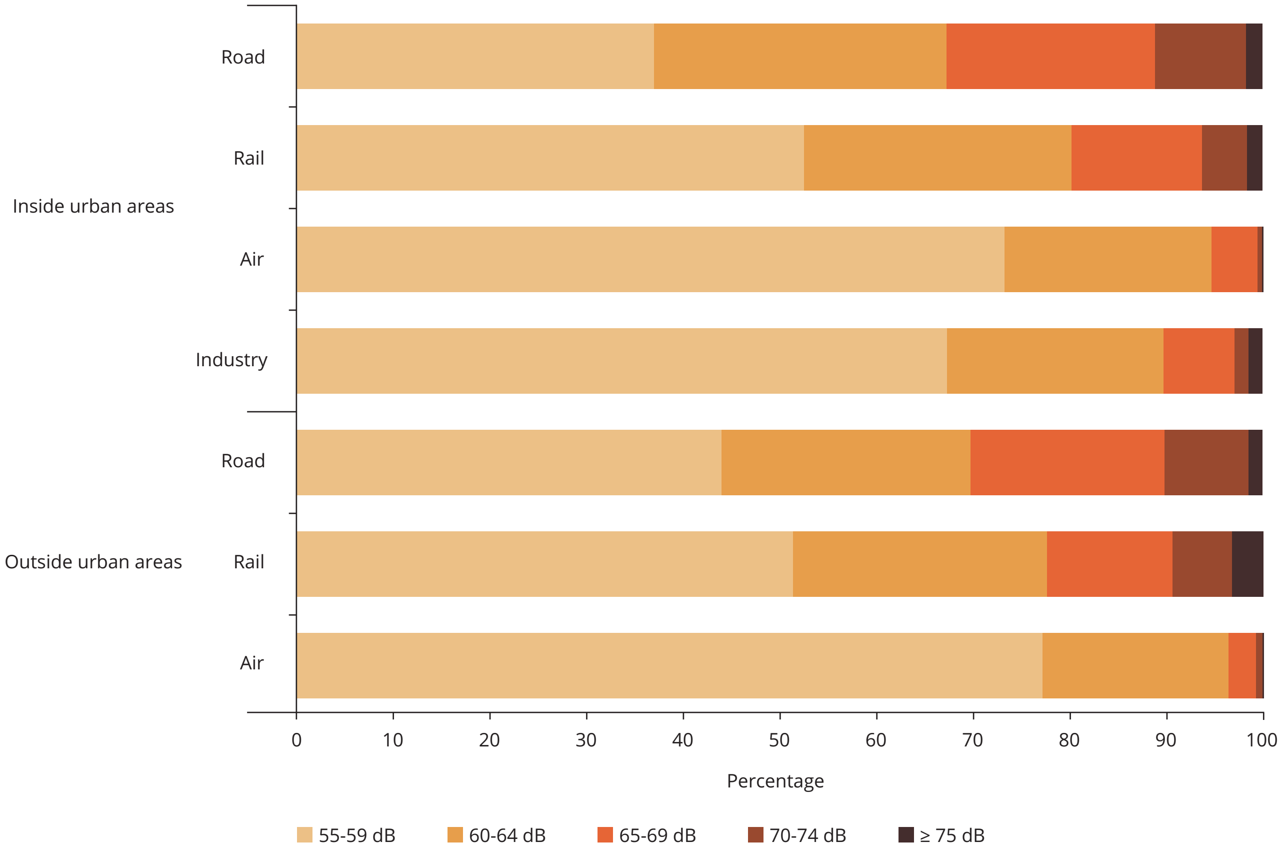
Figure 2.3 shows the exposure data, as reported by EEA member countries, for noise bands above 55 dB L_{den}. Most of the people are exposed to the lowest decibel band (55-60 dB). However, there is still a considerable number affected by higher levels of noise, in particular road traffic noise both inside and outside urban areas. Specifically, there are approximately 12 million people exposed to very high noise levels of road traffic noise equal to or higher than 70 dB L_{den}. Figure 2.4 shows that road traffic noise is the noise source with the highest percentage

Figure 2.3 Number of people exposed to various L_{den} noise bands based on areas covered by strategic noise maps in 2017, EEA-33 (Turkey not included)



Sources: EEA (2019d) and ETC/ATNI (2019b).

Figure 2.4 Distribution of the exposed population within each source, per noise band, using the L_{den} indicator in 2017, EEA-33 (Turkey not included)



Sources: EEA (2019d) and ETC/ATNI (2019b).

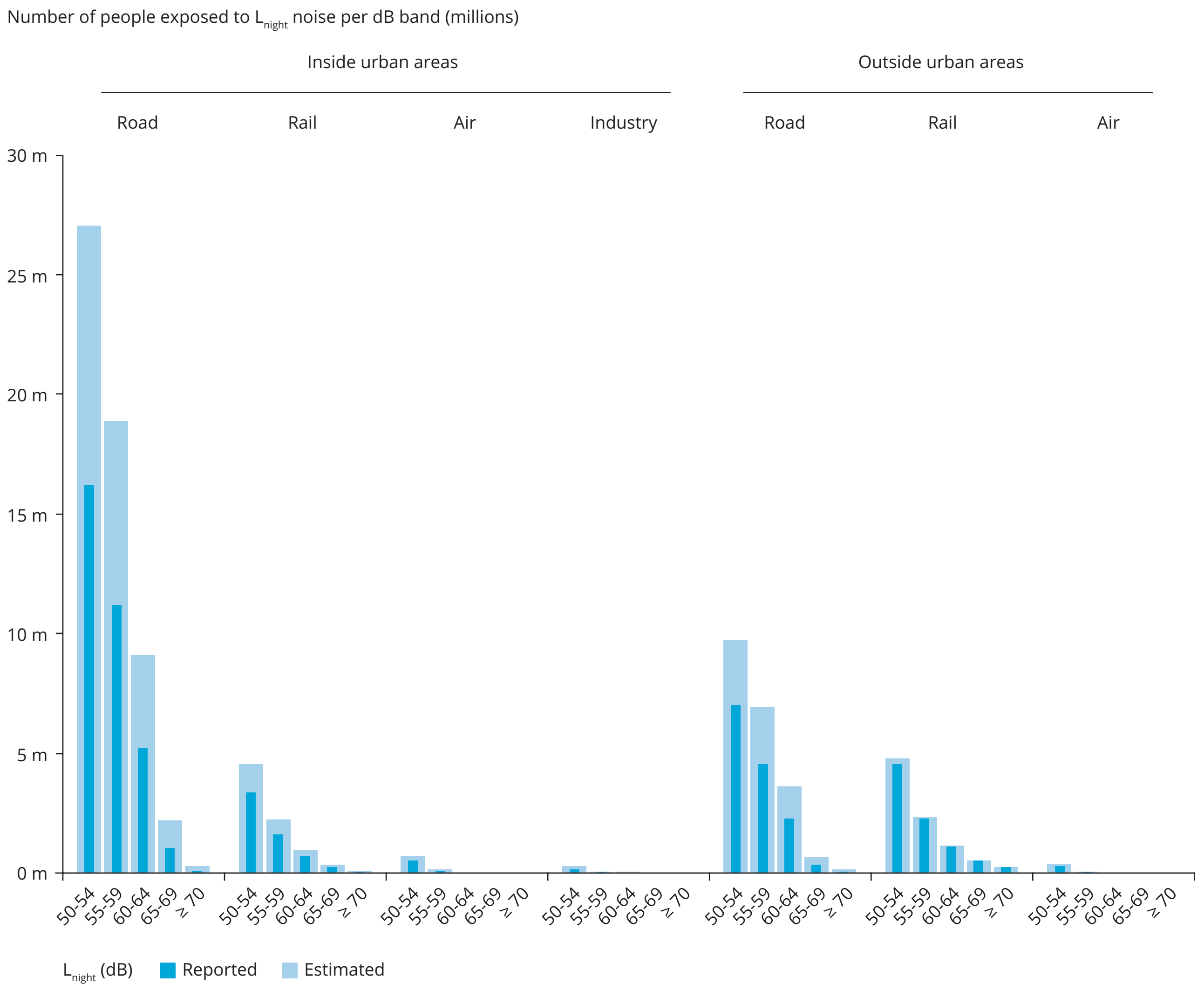
of people exposed to the upper bands, starting from 70 dB L_{den}. However, of the people exposed to aircraft noise both inside and outside urban areas, only a small proportion are exposed to the highest noise categories.

Night-time noise affects fewer people in the higher noise bands. As for the day-evening-night period, road traffic noise is the noise source that has the highest number of people exposed to very high levels of noise (≥ 65 dB) during the night-time (Figure 2.5).

However, as shown in Figure 2.6, railway noise is the source with the highest proportion of people exposed to levels falling in the upper bands of the spectrum (≥ 65 dB) during the night-time.

There is a considerable variability in the percentage of the population exposed to high noise levels within individual countries (Figure 2.7). For instance, the proportion of the population within a country exposed to road traffic noise inside and outside urban areas

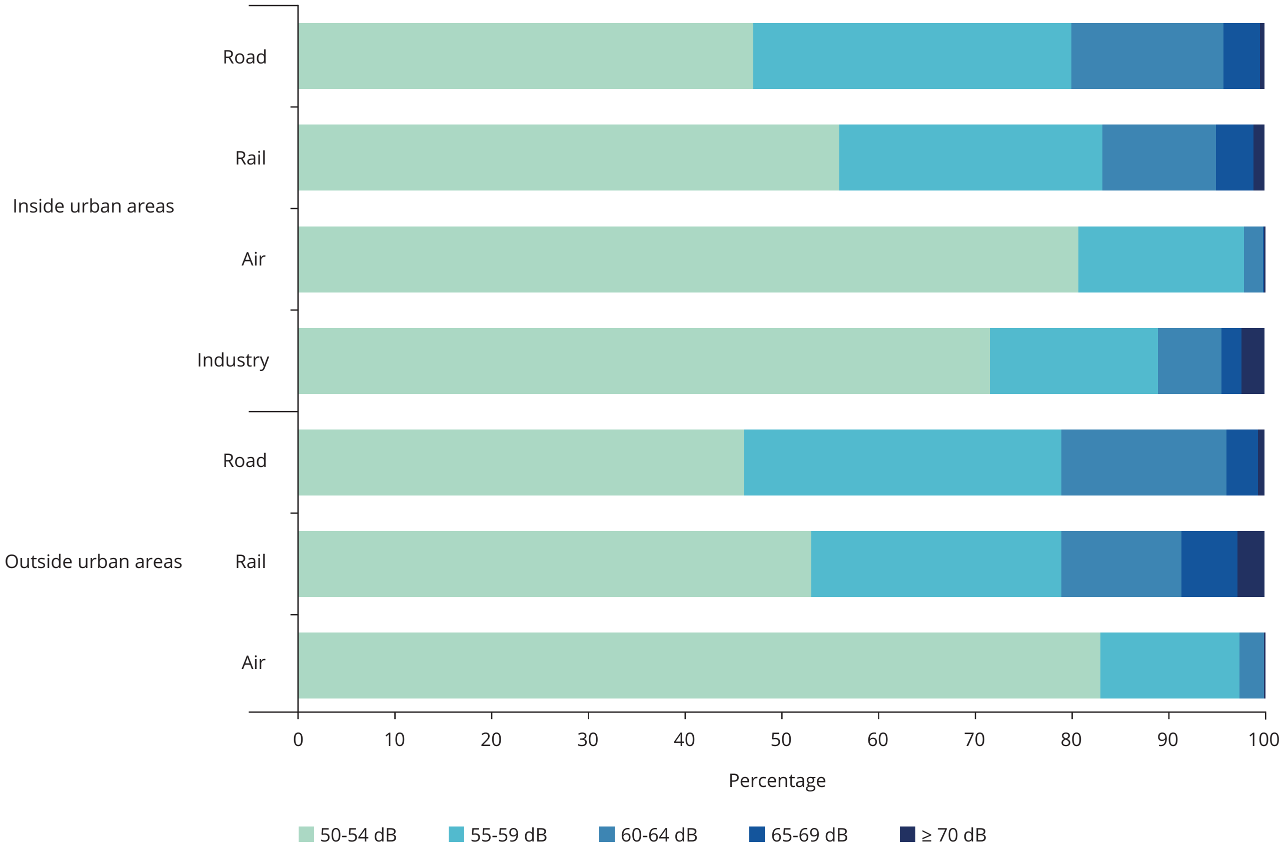
Figure 2.5 Number of people exposed to various L_{night} noise bands in areas covered by the strategic noise maps 2017, EEA-33 (Turkey not included)



Sources: EEA (2019d) and ETC/ATNI (2019b).

above 55 dB during the day-evening-night period ranges from 9 % in Slovakia to 54 % in Cyprus. The proportion in EEA member countries is 21 %. The variability among countries may be due to several factors, including the noise mapping method and approaches to estimating exposure, the density of transport networks, reporting completeness and internal policies in relation to noise management and control. For example, the END states that the reporting of data needs to be conducted in all agglomerations with a population in excess of 100 000 people and a population density such that the Member State considers them urbanised areas. Therefore, the extent of the variability partly depends on how they define density and how countries delimit agglomerations in their territories. For instance, Switzerland may have a high percentage of people exposed to road noise inside urban areas, as it reports

Figure 2.6 **Distribution of the exposed population within each source, per noise band, using the L_{night} indicator in 2017, EEA-33 (Turkey not included)**



Sources: EEA (2019d) and ETC/ATNI (2019b).

13 agglomerations according to its own agglomeration criteria. Conversely, countries with a similar population such as Portugal and Norway report six and five agglomerations, respectively. Map coverage differs between cities. For instance, in the city of Luxembourg, all streets are mapped for road noise, while in London only the busiest roads are mapped. Another cause of variability may be the density of transport networks across countries. For instance, in the central part of Europe (e.g. Austria, Belgium, France, Germany, Luxembourg and Switzerland), where the railway network is denser and well developed, a higher percentage of people are exposed to railways outside urban areas than in other countries.

Information on the strategic noise mapping in the EEA Western Balkan cooperating countries is shown in Box 2.2.

Figure 2.7 **Percentage of countries' total population exposed to L_{den} ≥ 55 dB in areas covered under the END 2017**

	Inside urban areas				Outside urban areas		
	Road	Rail	Air	Industry	Road	Rail	Air
Austria	24.2	6.6	0.1	0.1	8.2	5.7	0.1
Belgium	14.0*	1.0*	0.6*	0.2*	8.6	2.2	0.6*
Bulgaria	28.8*	0.6*	0.1*	0.0*	1.5		**
Croatia	7.7	0.6	0.0	0.0	2.8	0.0	
Cyprus	49.2*	3.2*	0.9*	1.0*	4.7*		
Czechia	16.7	0.7	0.1	0.0	6.9	1.8	0.1
Denmark	18.5	0.5*	0.1*	0.0*	5.0	1.5	0.0*
Estonia	22.7	0.5	0.2	0.2	0.5		
Finland	8.8	1.6	0.1*	0.0*	2.1	0.6	0.4
France	23.5*	3.6*	0.7*	0.2*	9.8	3.9	0.0*
Germany	6.9*	3.7	0.7	0.1*	3.3	4.0	0.4
Greece	7.9*	1.3*	0.4*	0.1*	0.2*	0.0*	0.0*
Hungary	16.4	1.3	0.0	0.0	1.8	0.9	0.3
Iceland	16.6		0.5*	0.2			0.5
Ireland	14.4	0.6	0.6		4.8	0.3	0.0
Italy	13.7*	0.9*	0.7*	0.1*	12.0*	3.3	0.3*
Latvia	27.0	2.0	0.0	0.7	1.2	0.1	0.1
Liechtenstein					11.4*		
Lithuania	26.3	0.4	0.4	0.3	0.8	0.0	
Luxembourg	24.5	1.5	10.1		11.2	3.3	1.1
Malta	22.4		1.9	0.0	3.7		
Netherlands	19.3	1.3	0.4	0.3	1.0	0.5	0.0
Norway	15.2*	2.2*	0.2*	0.0*	2.6*	0.2	0.1*
Poland	11.6	0.6*	0.1	0.1*	5.7	0.5	0.0
Portugal	5.2	0.4	0.9	0.0	8.6*	1.0	1.3
Romania	13.3*	1.5*	0.2*	1.2*	1.6*	0.1*	0.0*
Slovakia	6.7*	2.4*	0.0*	0.0*	2.9*	2.0*	
Slovenia	9.8	1.2		0.0	5.5	1.1	
Spain	24.8*	1.1*	0.2*	0.2*	4.2*	0.7*	0.3
Sweden	13.2	2.9	0.2*	0.0	3.3	2.7	0.2
Switzerland	30.6	3.4	1.1	0.2*	5.1	2.4	0.0
United Kingdom	14.5	1.9	1.5	0.2	6.5	0.7	0.2*
EEA-33	15.5*	2.0*	0.6*	0.2*	5.9*	2.1*	0.2*

* Data totally or partially estimated; ** Could not be estimated

Percentage of the population exposed to L_{den} ≥ 55 dB

0 — 50

Notes: EEA-33 average excludes Turkey. Ireland submitted updated data for air-related noise exposure after 1 January 2019. These new data are considered in this chart.

Sources: EEA (2019d) and ETC/ATNI (2019b).

Box 2.2 Strategic noise mapping in Western Balkan cooperating countries

The introduction of the Environmental Noise Directive (END) in Europe has attracted the attention of other countries in terms of applying strategic noise mapping approaches and action planning. Some of the EEA Western Balkan cooperating countries are in the process of implementing the directive.

For the third round of noise mapping in 2017, Bosnia and Herzegovina, Montenegro and North Macedonia have submitted information regarding all the noise sources to be mapped. However, strategic noise maps have been delivered only for the city of Podgorica in Montenegro (see table below). The mapping, which shows that a considerable percentage of the population is exposed to levels beyond the END thresholds for road traffic noise, highlights the importance of strategic noise mapping as an approach to reducing harmful effects. To tackle the noise problem, the city of Podgorica has recently adopted noise action plans that will help protect people from environmental noise.

Number of people exposed to noise (percentage of people exposed to noise) in Podgorica, Montenegro

Noise source	L_{den} ≥ 55 dB	L_{night} ≥ 50 dB
Road noise	132 500 (71 %)	117 200 (63 %)
Rail noise	6 700 (4 %)	5 500 (3 %)

2.2 Road traffic noise

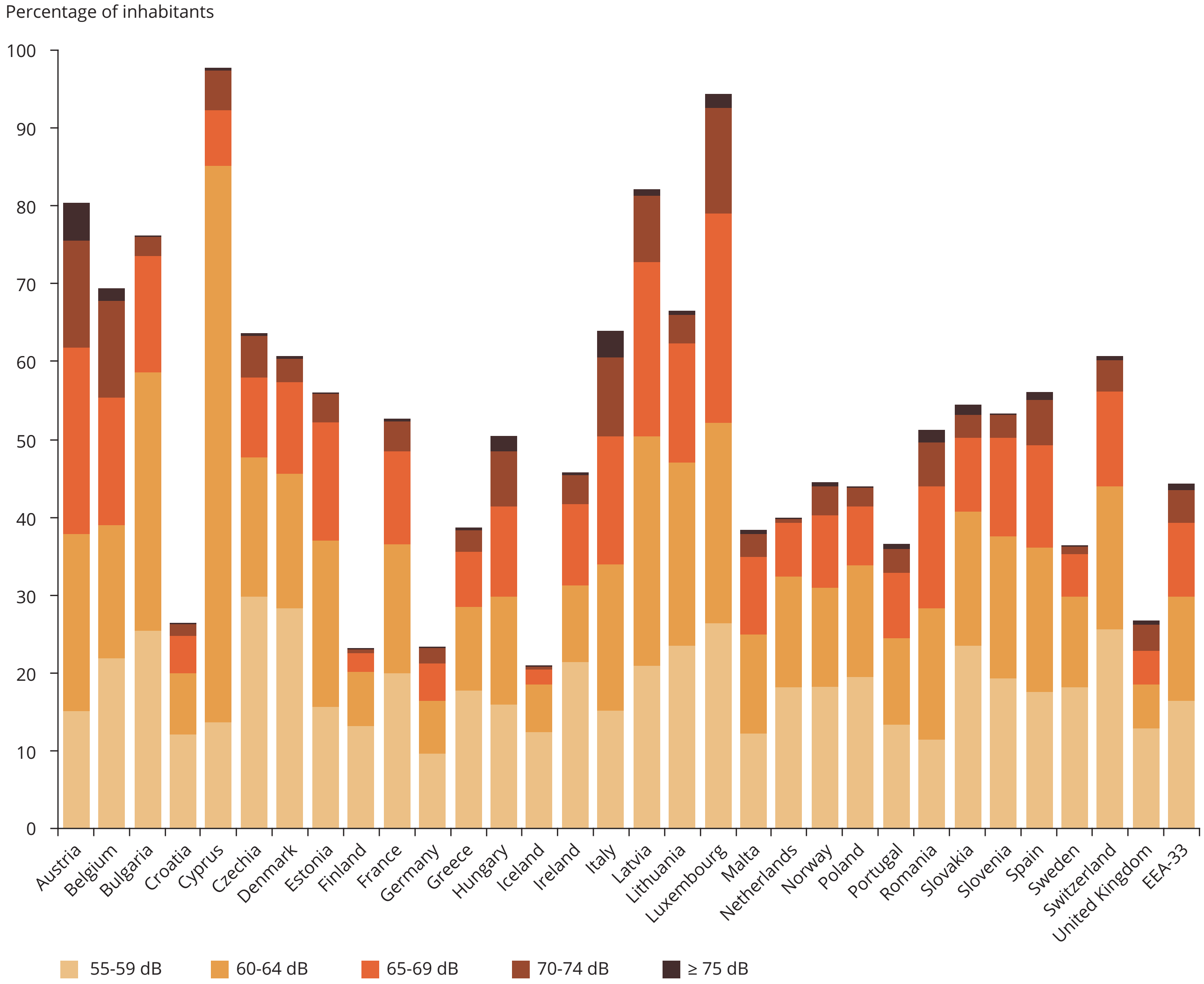
The number of people exposed to noise from road traffic far exceeds that exposed to rail, aircraft and industry sources. This is true at the European level, at the country level and both inside and outside urban areas. This is due to the extent of the road network, which is greater than that of other noise sources. For instance, under the terms of the END, countries need to assess noise levels for 420 791 km of major roads with more than 3 million vehicle passages a year as well as all roads within 511 urban areas. Moreover, the use of road vehicles is very widespread in the EU, with approximately 500 cars per 1 000 inhabitants (ACEA, 2017).

It is estimated that approximately 82 million people are affected by levels of road traffic noise of at least 55 dB during the day-evening-night period inside urban areas. Adding to this figure, the estimated number of people exposed to major roads outside urban areas is estimated to be 31 million. In terms of night-time noise, the figures are 57 million and 21 million, respectively. This means that at least 20 % of the population during the day-evening-night period and 15 % during the night-time period are exposed to high levels of road traffic noise. These values are expected to be higher, given that the END does not comprehensively cover all urban areas or all roads across Europe (Figure 2.2).

A wide range of variation can be identified among countries in the number of people exposed to road traffic noise inside urban areas. Figure 2.8 shows that, for example, most of the countries have more than 50 % of inhabitants within urban areas exposed to road noise levels of 55 dB L_{den} or higher during the day-evening-night period.

For agglomerations, there are also considerable differences when comparing urban areas within the same country. Larger cities in general have a higher

Figure 2.8 **Estimated percentage of inhabitants within urban areas exposed to road traffic noise bands in 2017, using the L_{den} indicator**



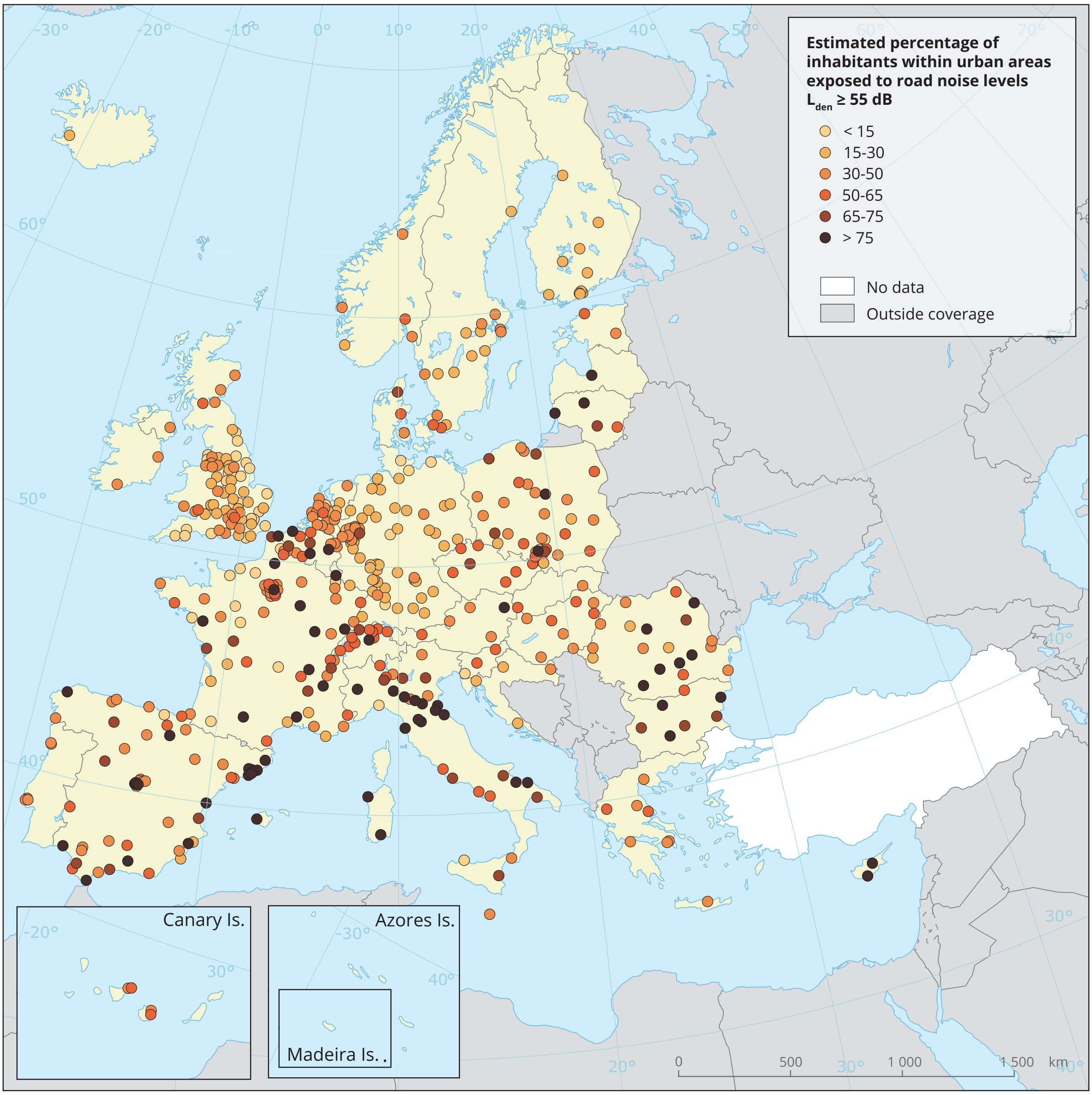
Notes: Liechtenstein does not have agglomerations under the terms of the END. EEA-33 average excludes Turkey.

Sources: EEA (2019d) and ETC/ATNI (2019b).

number of people exposed to high levels of road traffic noise, although it is not always the case. For instance, not all capital cities have the highest percentage of people exposed to road noise levels above the END threshold. This may be a result of splitting large urban areas into smaller agglomeration units. The correlation between the size of the road network and the density of the city and the number of people exposed to road traffic noise is only small but significant.

Map 2.1 shows the proportion of inhabitants within urban areas exposed to high levels of road noise of at least 55 dB for the day-evening-night period. In countries such as Finland, Germany, Norway, Sweden and the United Kingdom, the proportion of people exposed to road traffic noise across different cities in the same country is rather homogeneous. However, in southern and eastern European countries, the differences in the proportion of people exposed to noise seem to differ greatly from city to city within the same country. The north-east of Spain and the north of Italy in particular seem to have a very high percentage of people exposed to levels above the END thresholds. Belgium, Bulgaria, Lithuania and Romania also have a considerable number of urban areas within their territories, with a high percentage of people exposed to noise levels above the END thresholds. In terms of capital cities, Figure 2.9 shows the high variability in population exposure to noise due to road traffic. These results may be explained by several reasons, including the use of different methodological approaches to noise mapping within countries. For instance, in the city of Luxembourg all streets are mapped, while in some other cities only the busiest roads are mapped. The proportion of a country's population exposed to major roads outside urban areas is shown in Map 2.2. The proportion of people exposed to noise from major roads ranges from less than 1 % — in the case of the Netherlands, Lithuania, Greece and Estonia — to 10-12 % — in the case of Italy, Liechtenstein and Luxembourg.

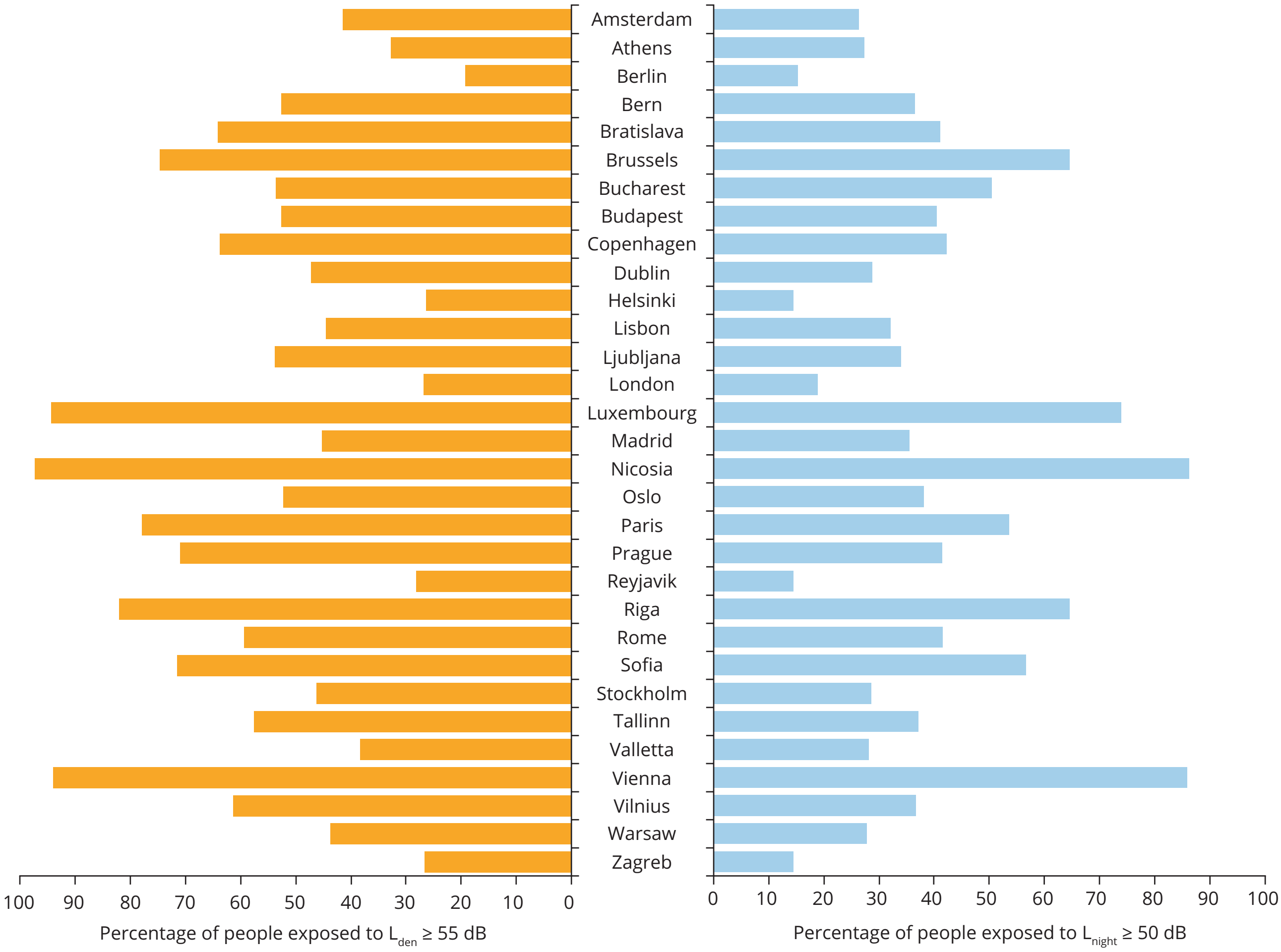
Map 2.1 Estimated percentage of inhabitants within urban areas, exposed to road noise levels $L_{den} \geq$ 55 dB in 2017



Note: Liechtenstein does not have agglomerations under the terms of the END.

Sources: EEA (2019d) and ETC/ATNI (2019b).

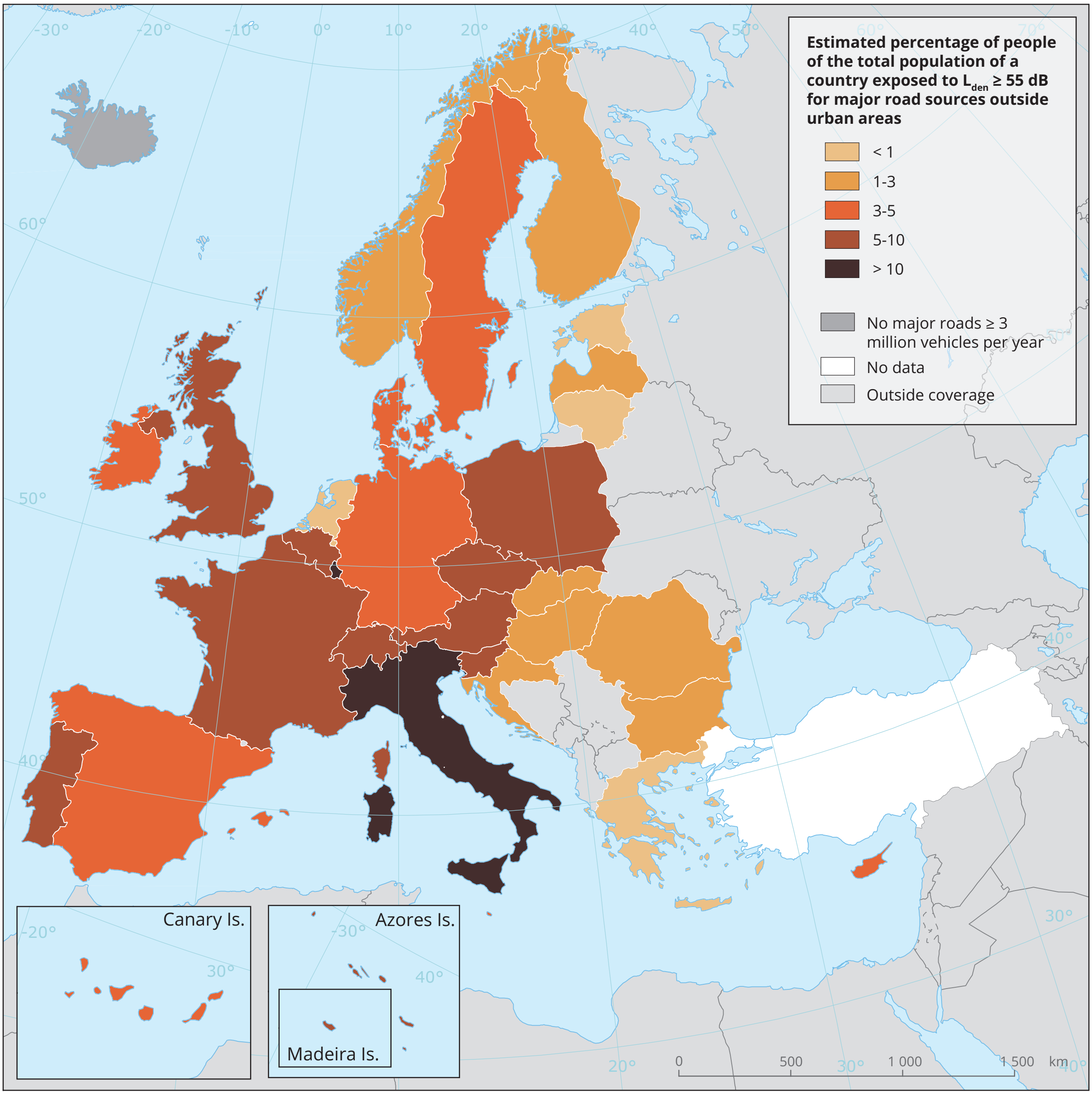
Figure 2.9 Estimated percentage of people exposed to road traffic noise $L_{den} \geq 55$ dB and $L_{night} \geq 50$ dB in capital cities, 2017



Note: Liechtenstein does not have agglomerations under the terms of the END.

Source: EEA (2019d) and ETC/ATNI (2019b).

Map 2.2 **Estimated percentage of the total population of a country exposed to L_{den} ≥ 55 dB for major road sources outside urban areas in 2017**



Sources: EEA (2019d) and ETC/ATNI (2019b).

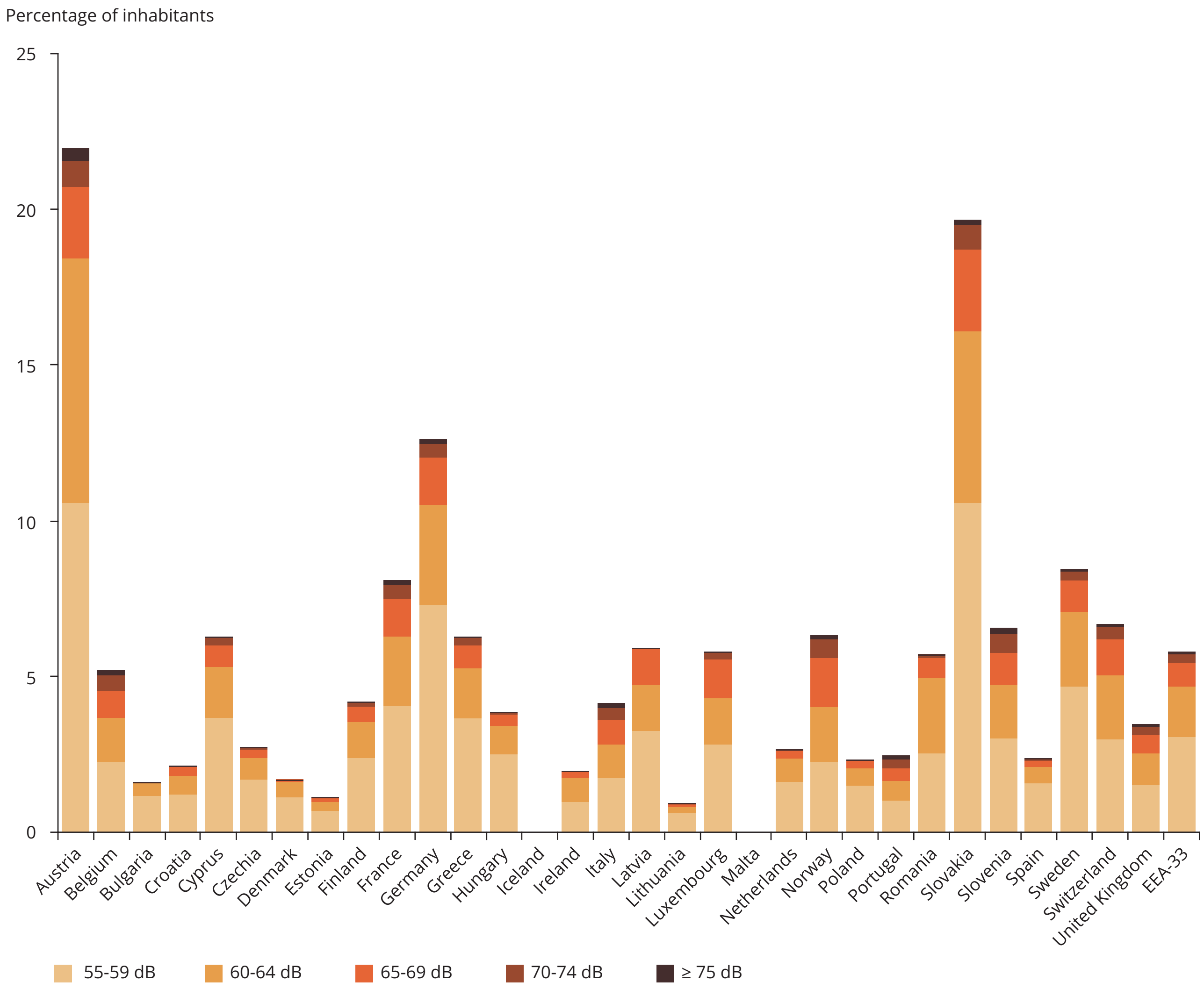
2.3 Rail traffic noise

Rail traffic is the second most dominant source of environmental noise in Europe, with nearly 22 million people estimated to be exposed to rail traffic noise of at least 55 dB during the day-evening-night period. Of those, 11 million are exposed to railway noise sources within urban areas and 11 million are exposed to major railway noise sources outside urban areas. Night-time railway noise of 50 dB or higher affects approximately 9 million people inside urban areas and 8 million people outside urban areas. As a result, it is estimated that railway noise above the END thresholds affects 4 % of the population during the day-evening-night period and 3 % during the night-time period.

The number of people exposed to rail traffic noise inside urban areas is highly correlated with the number of city inhabitants and varies between countries. The central part of Europe is where a higher number of people inside urban areas are exposed to railway noise levels of at least 55 dB L_{den}. On average, at the European level, 6 % of people living inside urban areas are exposed to rail traffic noise of at least 55 dB L_{den}, with more than 10 % of urban inhabitants in Austria, Germany and Slovakia exposed to railway traffic noise above the END day-evening-night reporting threshold (Figure 2.10).

In terms of the proportion of people exposed to railway noise, the highest proportions are also seen in urban areas in countries in the central part of Europe (Map 2.3). The proportional differences in exposure to railway noise across cities could be due to whether or not urban trams and light railways are included in the noise mapping exercise. For instance, the proportion of people exposed to rail traffic noise above the END thresholds is greatest in capital cities such as Bratislava, Bucharest, Paris and Vienna all of which have a developed network of trams or an overground rail network.

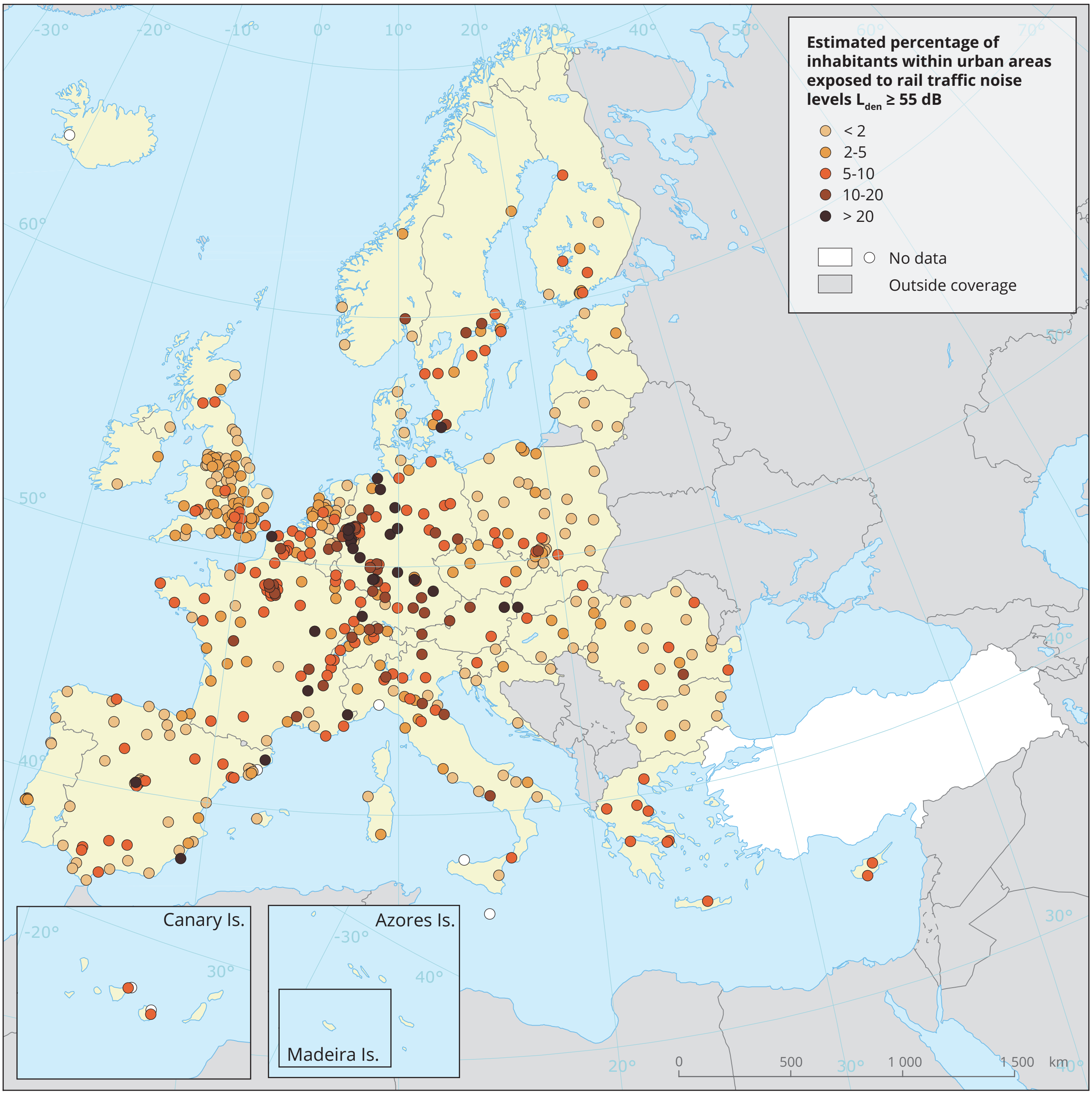
Figure 2.10 Estimated percentage of inhabitants within urban areas exposed to rail traffic noise bands in 2017, using the L_{den} indicator



Notes: Liechtenstein does not have agglomerations under the terms of the END. EEA-33 average excludes Turkey.

Sources: EEA (2019d) and ETC/ATNI (2019b).

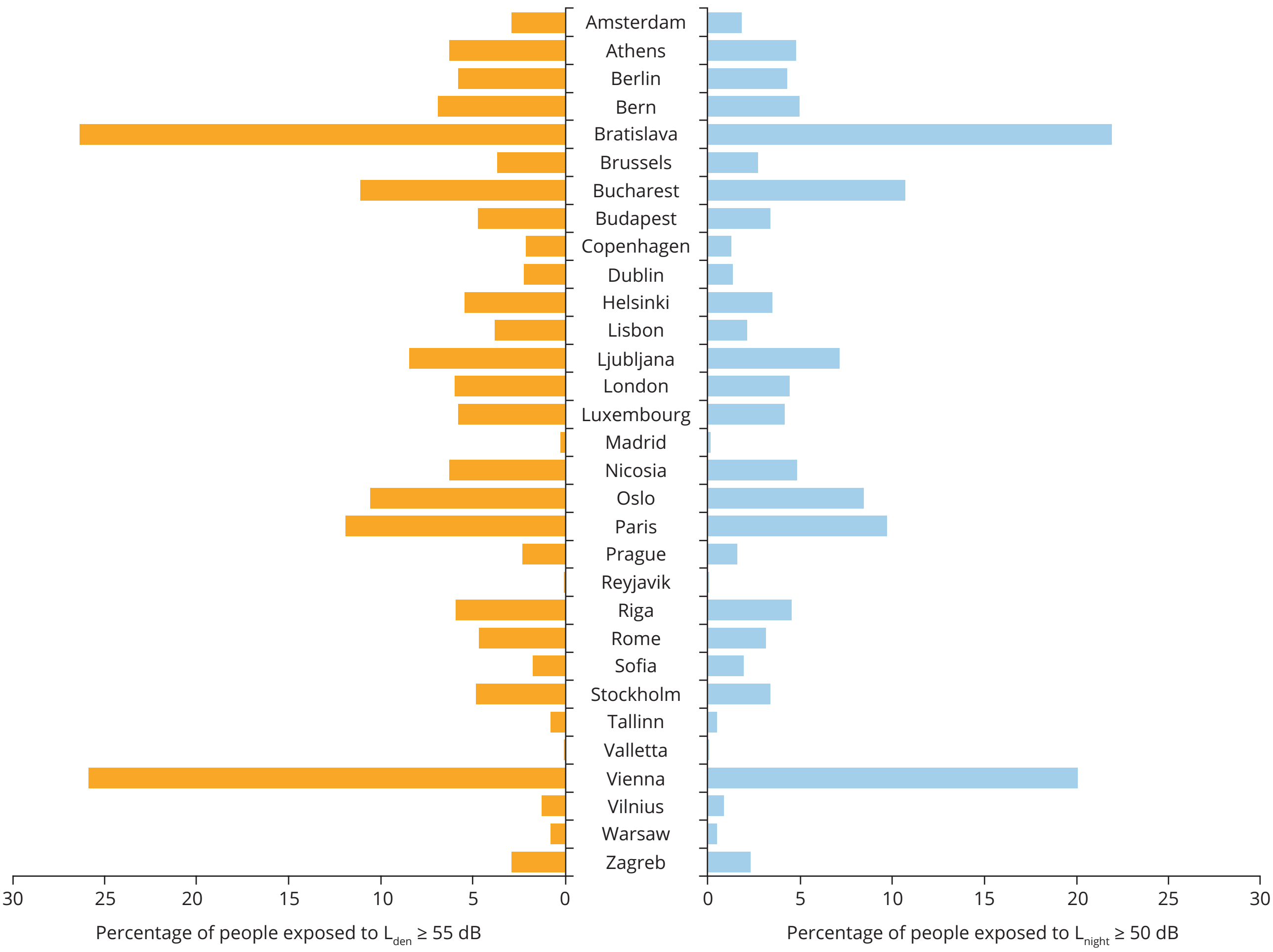
Map 2.3 **Estimated percentage of inhabitants within urban areas, exposed to rail traffic noise levels $L_{den} \geq 55$ dB in 2017**



Note: Liechtenstein does not have agglomerations under the terms of the END.

Sources: EEA (2019d) and ETC/ATNI (2019b).

Figure 2.11 Percentage of people exposed to rail traffic noise L_{den} ≥ 55 dB and L_{night} ≥ 50 dB in capital cities, 2017

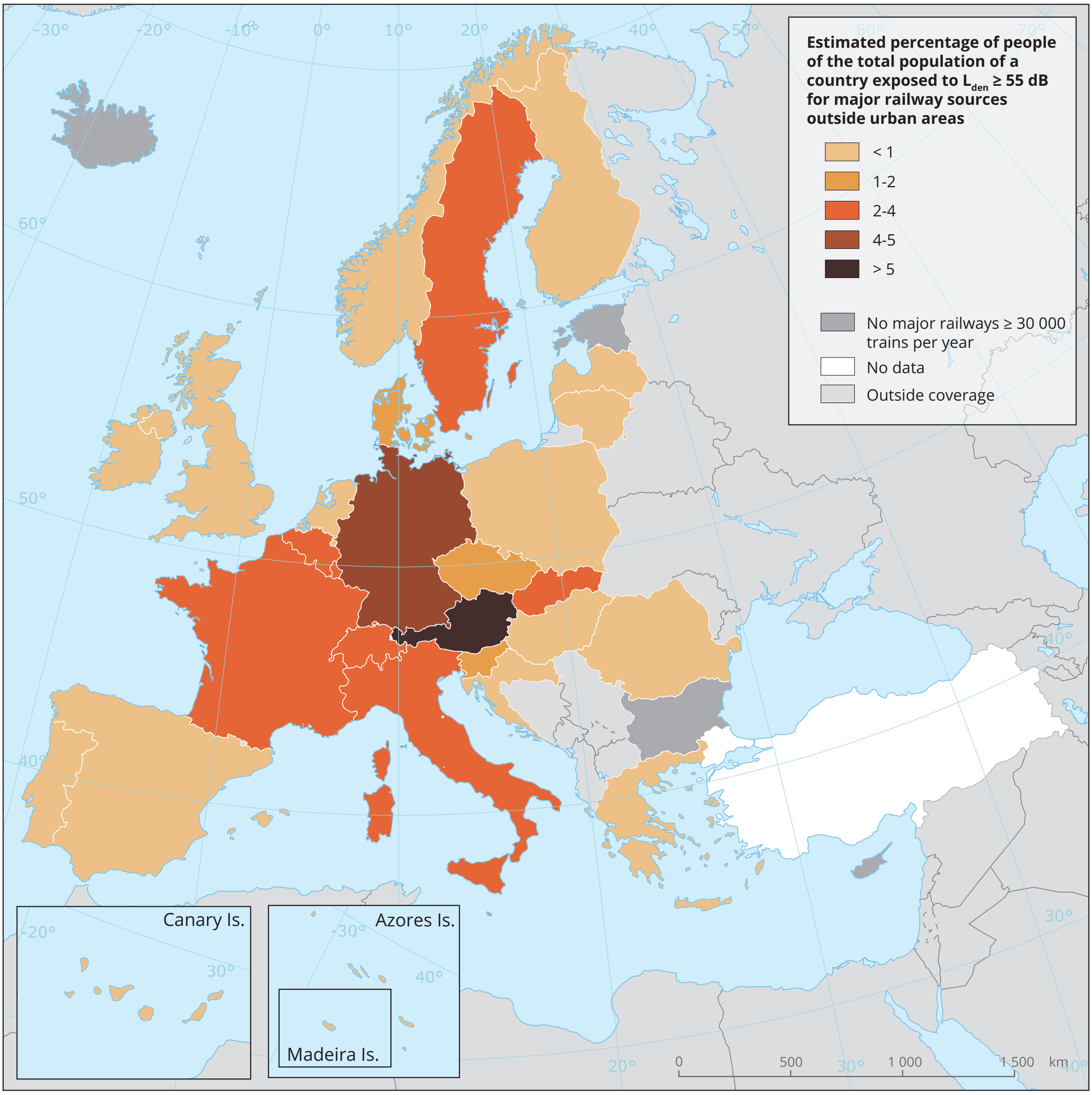


Note: Liechtenstein does not have agglomerations under the terms of the END.

Source: EEA (2019d) and ETC/ATNI (2019b).

The percentage of the total population of a country exposed to major sources of rail traffic is highest in the central European countries and ranges from less than 0.5 % in Croatia, Greece, Hungary, Ireland, Latvia, Lithuania, Norway and Romania to 4-5 % in Austria and Germany (Map 2.4). Countries such as Austria, Czechia, France, Germany, Switzerland and the United Kingdom have a larger number of railways that exceed 30 000 passages a year.

Map 2.4 **Estimated percentage of the total population of a country exposed to L_{den} ≥ 55 dB for major railway sources outside urban areas in 2017**



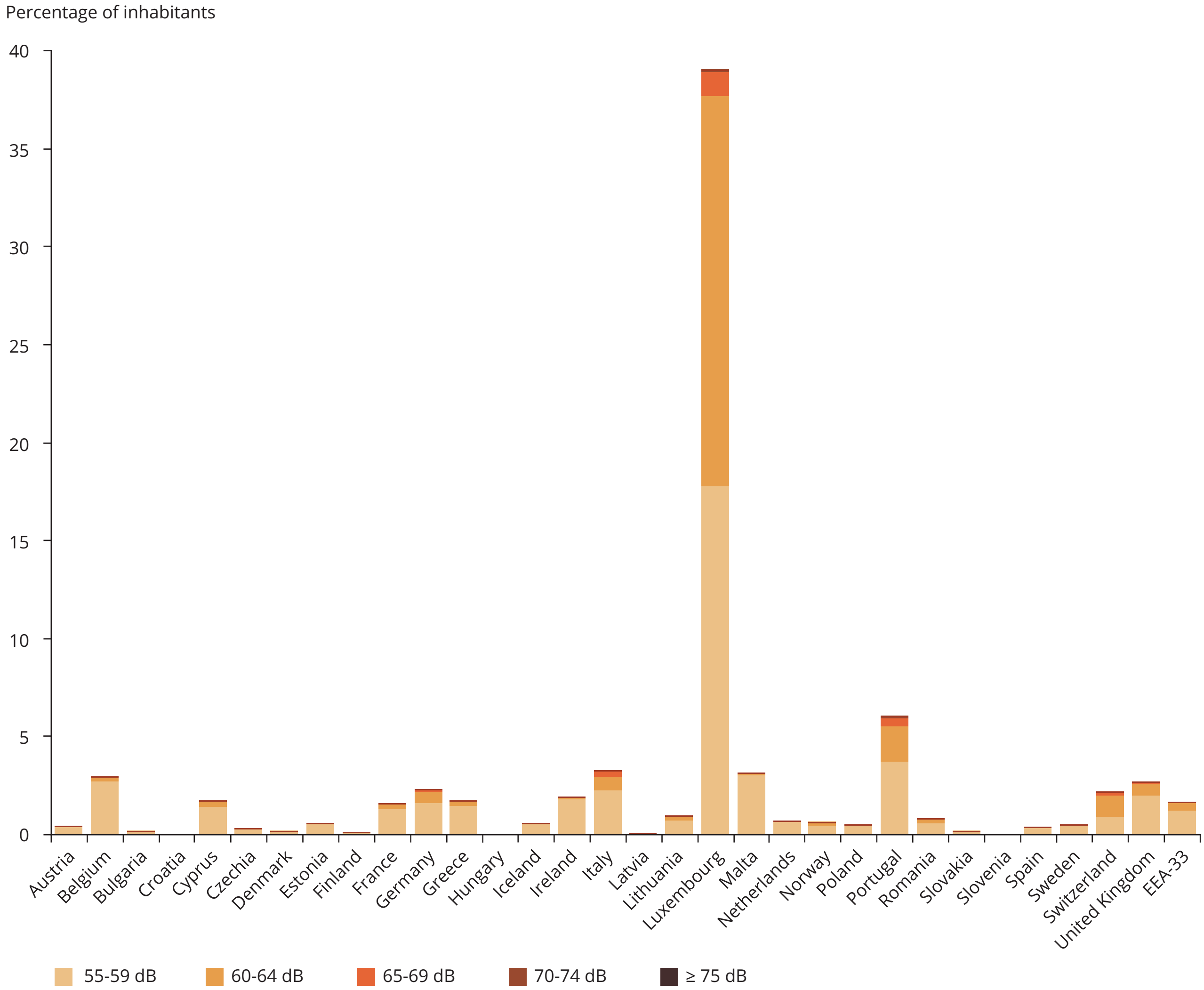
Sources: EEA (2019d) and ETC/ATNI (2019b).

2.4 Air traffic noise

Under the terms of the END, air traffic noise is defined as noise caused by aircraft landings and take-offs in the areas surrounding airports. Therefore, air traffic noise affects a much smaller proportion of the population than road or rail traffic noise. In total, there are 89 major airports covered under the END for which population exposure to noise is to be assessed.

According to current data, it is estimated that aircraft noise exposes approximately 3 million people to levels of 55 dB or higher during the day-evening-night period inside urban areas. Adding to this figure, the number of people exposed to noise from major airports outside urban areas is estimated to be 1 million. In terms of night-time noise, the figures are 1 and 0.5 million, respectively. These values represent a very small proportion of the total EU population. However,

Figure 2.12 Estimated percentage of inhabitants within agglomerations exposed to air traffic noise bands in 2017, using the L_{den} indicator



Notes: Liechtenstein does not have agglomerations under the terms of the END. EEA-33 average excludes Turkey. Ireland submitted updated data for air-related noise exposure after 1 January 2019. These new data are considered in this chart.

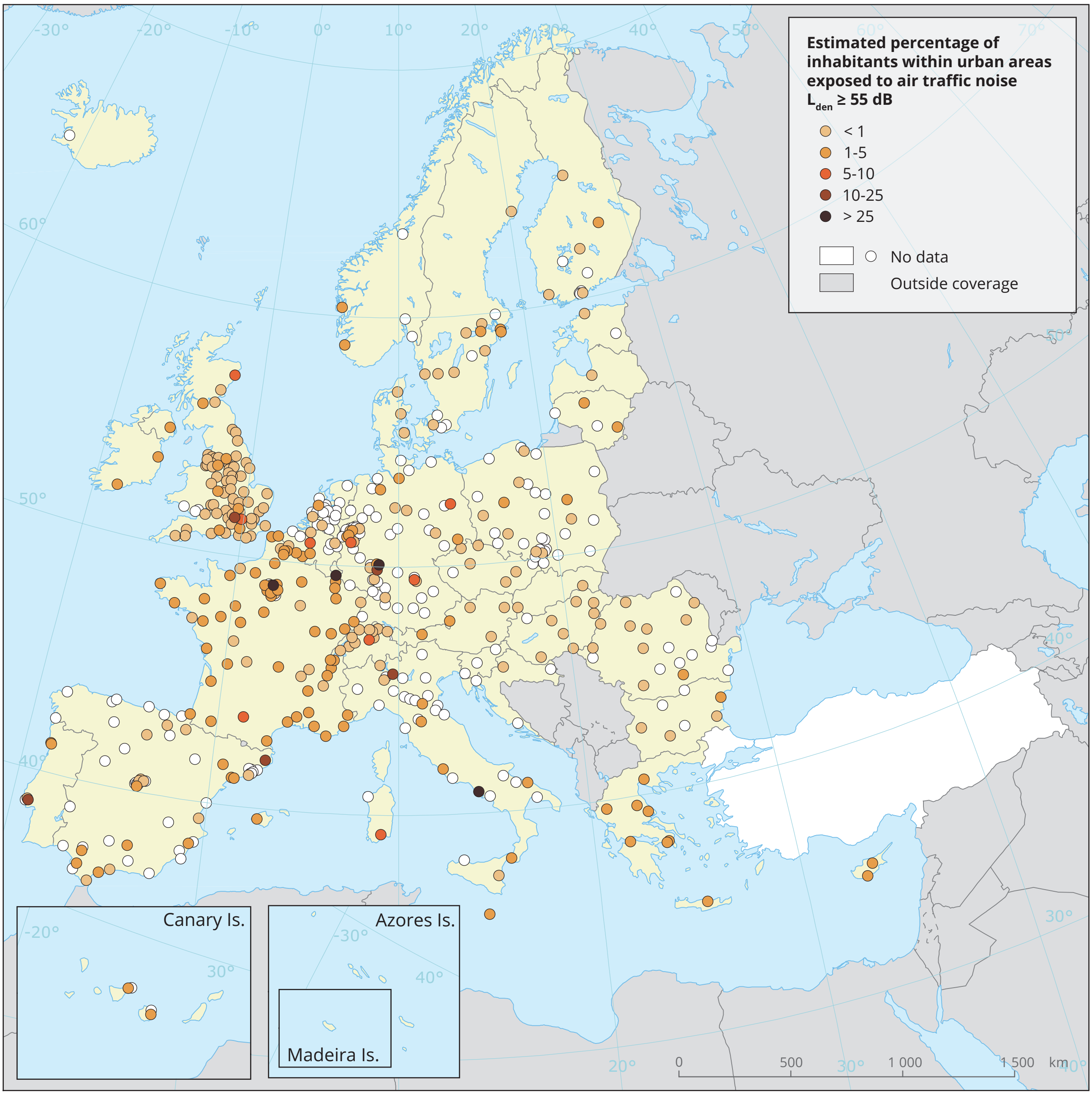
Sources: EEA (2019d) and ETC/ATNI (2019b).

it is an important source of noise, because it is regarded as more annoying than road or railway noise (Chapter 3).

Figure 2.12 indicates that the countries with the largest proportion of people exposed to aircraft noise inside urban areas above 55 dB L_{den} are Belgium, Italy, Luxembourg, Malta and Portugal with the EEA average at 2 %. These results probably depend to some extent on the number of airports within a country as well as how far airports are from urbanised areas. For instance, in France, Germany, Italy, Spain and the United Kingdom there are many more airports than in the rest of the countries, which generally have between one and three airports, depending on the size of the country. The striking difference between Luxembourg and the other countries is because data from only one agglomeration that is exposed to noise from a major airport are reported, whereas the data from other, larger countries represents an average over all agglomerations, including those that are not exposed to aircraft noise. It can also be seen that exposure to aircraft noise in the higher noise bands (≥ 70 dB) is not present in most of the countries.

Larger urban areas generally have more people exposed to aircraft noise. Not surprisingly, capital cities such as Amsterdam, Berlin, Brussels, Lisbon, London, Luxembourg or Rome appear to have more people exposed to aircraft noise levels of at least 55 dB L_{den}. However, urban areas with the highest number of people exposed to aircraft noise do not

Map 2.5 **Estimated percentage of inhabitants within urban areas exposed to air traffic noise L_{den} ≥ 55 dB in 2017**



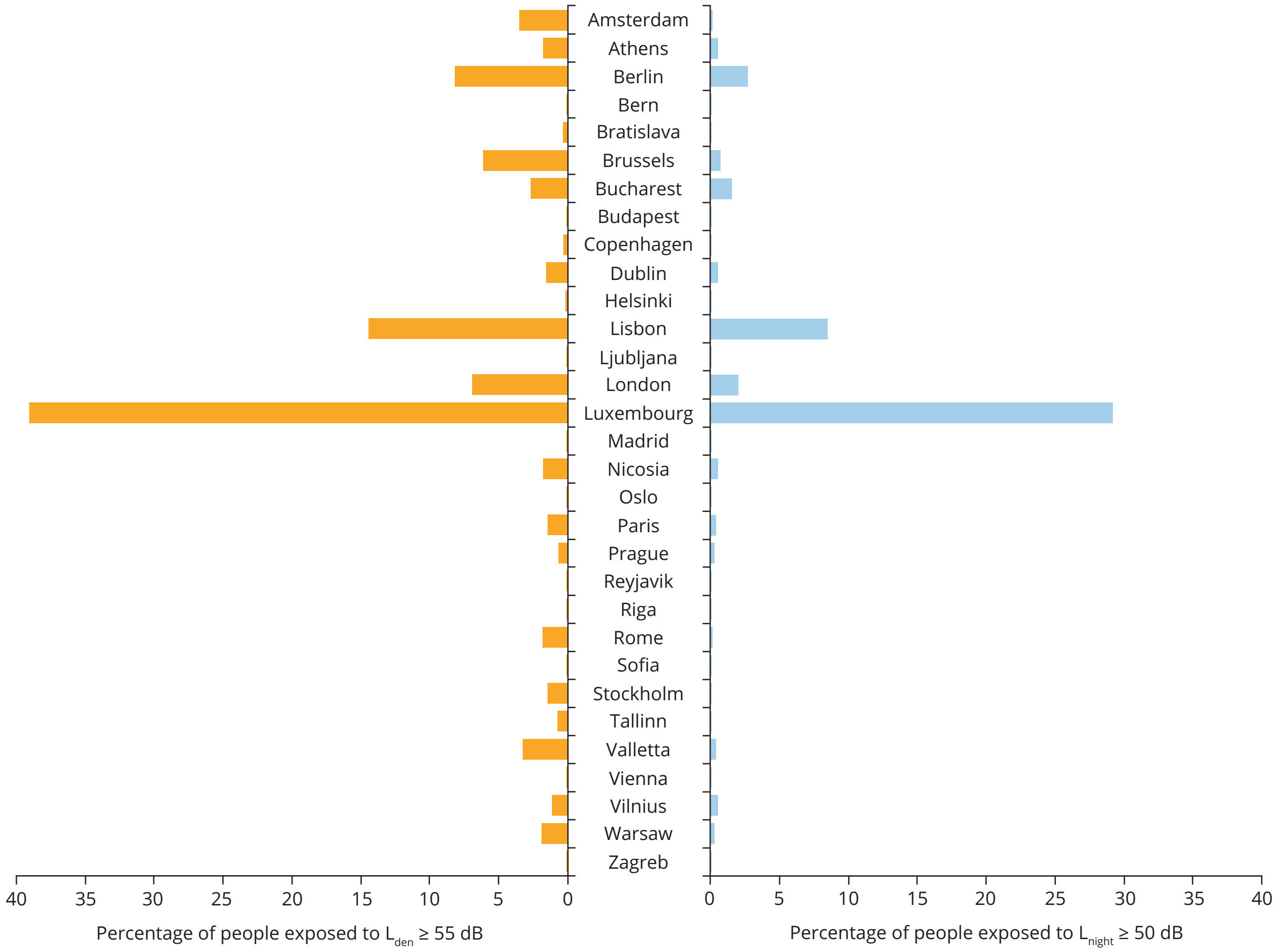
Note: Liechtenstein does not have agglomerations under the terms of the END.

Source: EEA (2019d) and ETC/ATNI (2019b).

systematically coincide with urban areas with the highest percentage of people exposed to day-evening-night levels of 55 dB or higher (Map 2.5). For instance, this variability may also depend on aircraft traffic volumes as well as local factors such as location and the surroundings of an airport. Capital cities such as Berlin, Lisbon, London and Luxembourg have the highest proportion of people exposed to aircraft noise (Figure 2.13).

Map 2.6 shows the estimated total number of people, inside and outside urban areas exposed to aircraft noise from major airports during the day-evening-night period. The major airports exposing the highest number of people to air traffic noise are London Heathrow, Lisbon Portela, Berlin Tegel and Frankfurt am Main.

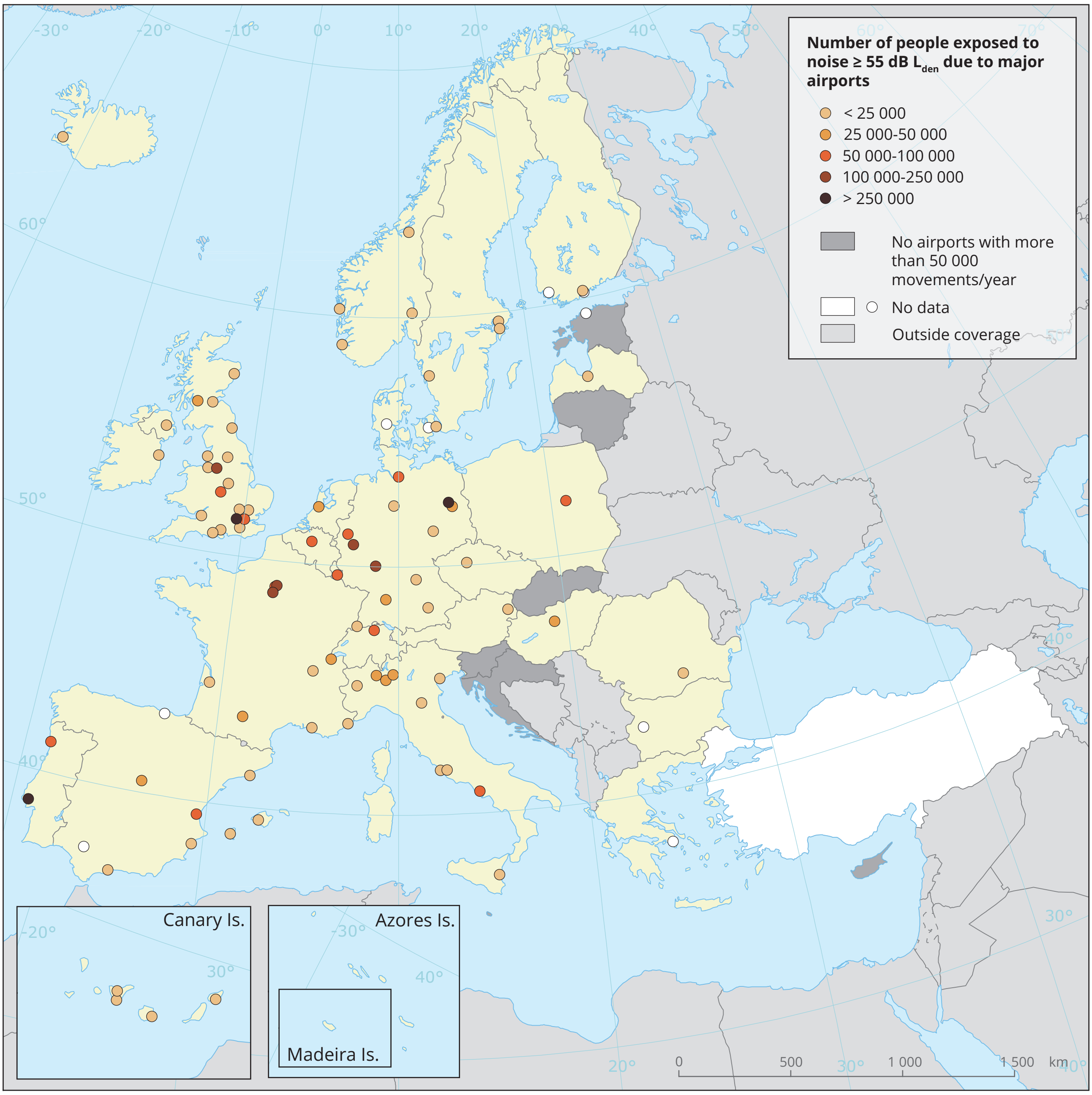
Figure 2.13 Percentage of people exposed to air traffic noise L_{den} ≥ 55 dB and L_{night} ≥ 50 dB in capital cities, 2017



Notes: Liechtenstein does not have agglomerations under the terms of the END.

Sources: EEA (2019d) and ETC/ATNI (2019b).

Map 2.6 **Estimated number of people exposed to L_{den} ≥ 55 dB due to major airports inside and outside urban areas in 2017**



Note: Ireland submitted updated data for air-related noise exposure after 1 January 2019. These new data are considered in this chart.

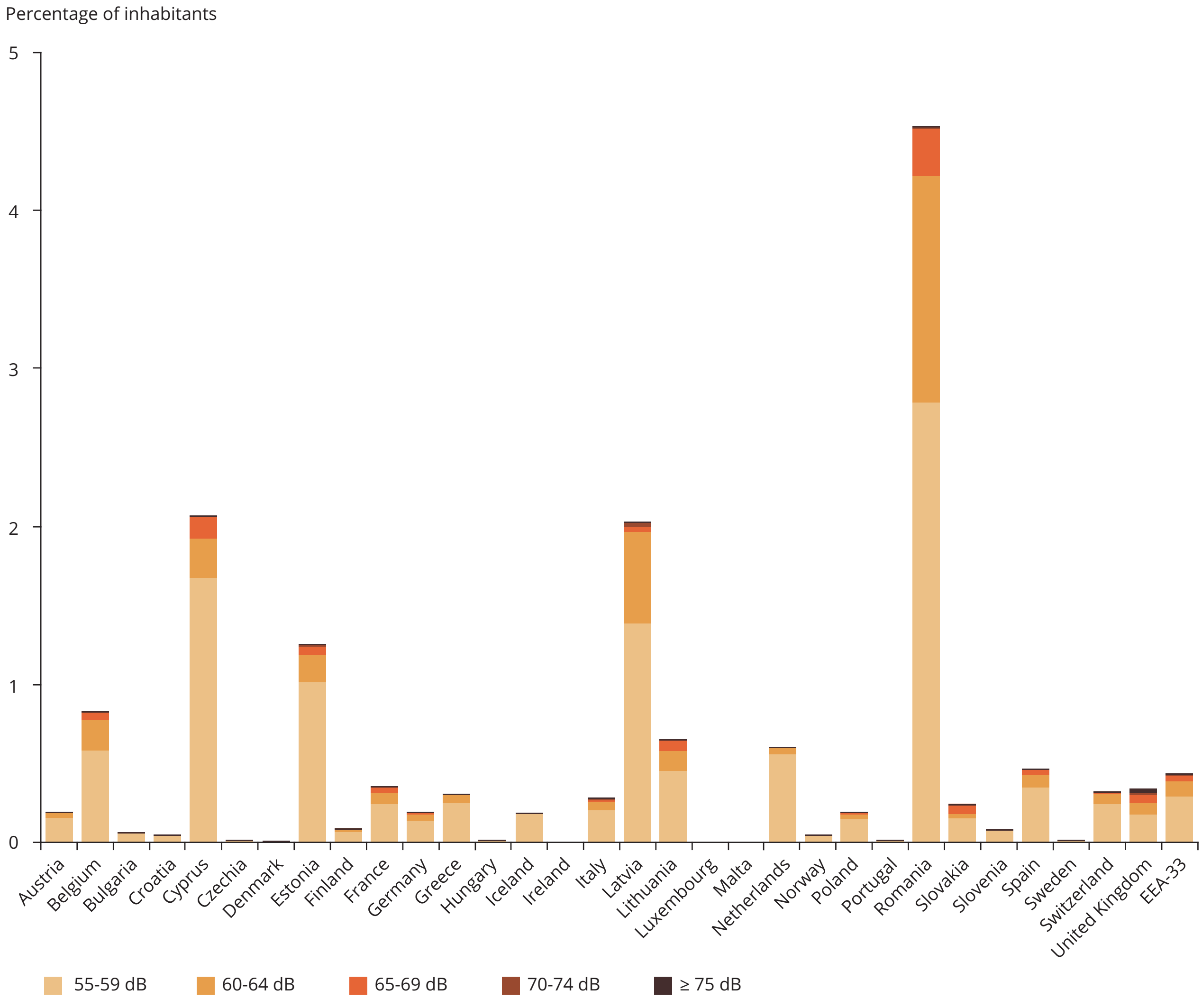
Sources: EEA (2019d) and ETC/ATNI (2019b).

2.5 Industrial noise

Strategic noise maps within urban areas defined under the END must include noise from sites of industrial activity, including ports. It is estimated that around 800 000 people living in urban areas are exposed to industry noise levels of at least 55 dB during the day-evening-night period and around 400 000 to levels of at least 50 dB during the night-time period. As a result, it is estimated that industry noise above the END reporting thresholds affects 0.15 % of the population inside urban areas during the day-evening-night period and 0.08 % during the night-time period. Therefore, industrial noise is by far the smallest contributor to population noise exposure compared with other noise sources.

The percentage of urban dwellers exposed to industrial noise reaches an average of 0.2 % for the EEA-33 member countries (Figure 2.14). Capital cities estimated to have the highest proportion of people exposed to noise from industry sources are Bucharest, Nicosia, Riga and Tallinn (Figure 2.15). However, as shown in Map 2.7, cities with a higher proportion of people exposed to industrial noise are generally not capital cities. The values range from highs of 18 % in cities such as Jerez de la Frontera to lows of 0 % in Innsbruck, where nobody is exposed, despite the existence of industrial noise. It is important to note that industrial sites and ports can be located in the outskirts of cities. Therefore, the way in which countries delimitate and define agglomerations under the END may have an effect on the number of people exposed to industrial noise.

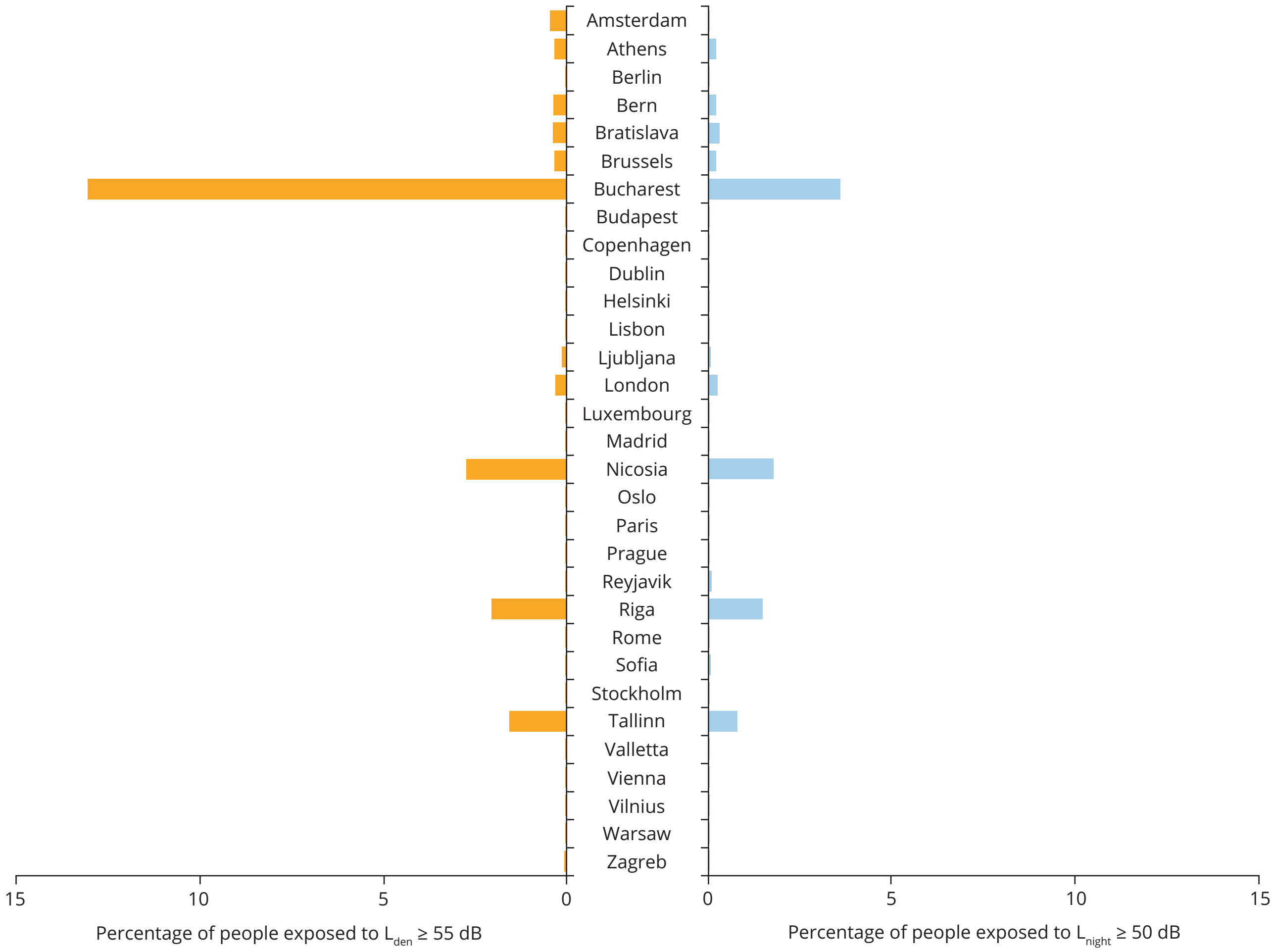
Figure 2.14 Estimated proportion of inhabitants within agglomerations exposed to industrial noise in 2017, using the L_{den} indicator



Note: Liechtenstein does not have agglomerations under the terms of the END. EEA-33 average excludes Turkey.

Sources: EEA (2019d) and ETC/ATNI (2019b).

Figure 2.15 **Percentage of people exposed to industrial noise L_{den} ≥ 55 dB and L_{night} ≥ 50 dB in capital cities, 2017**



Note: Liechtenstein does not have agglomerations under the terms of the END.

Source: EEA (2019d) and ETC/ATNI (2019b).

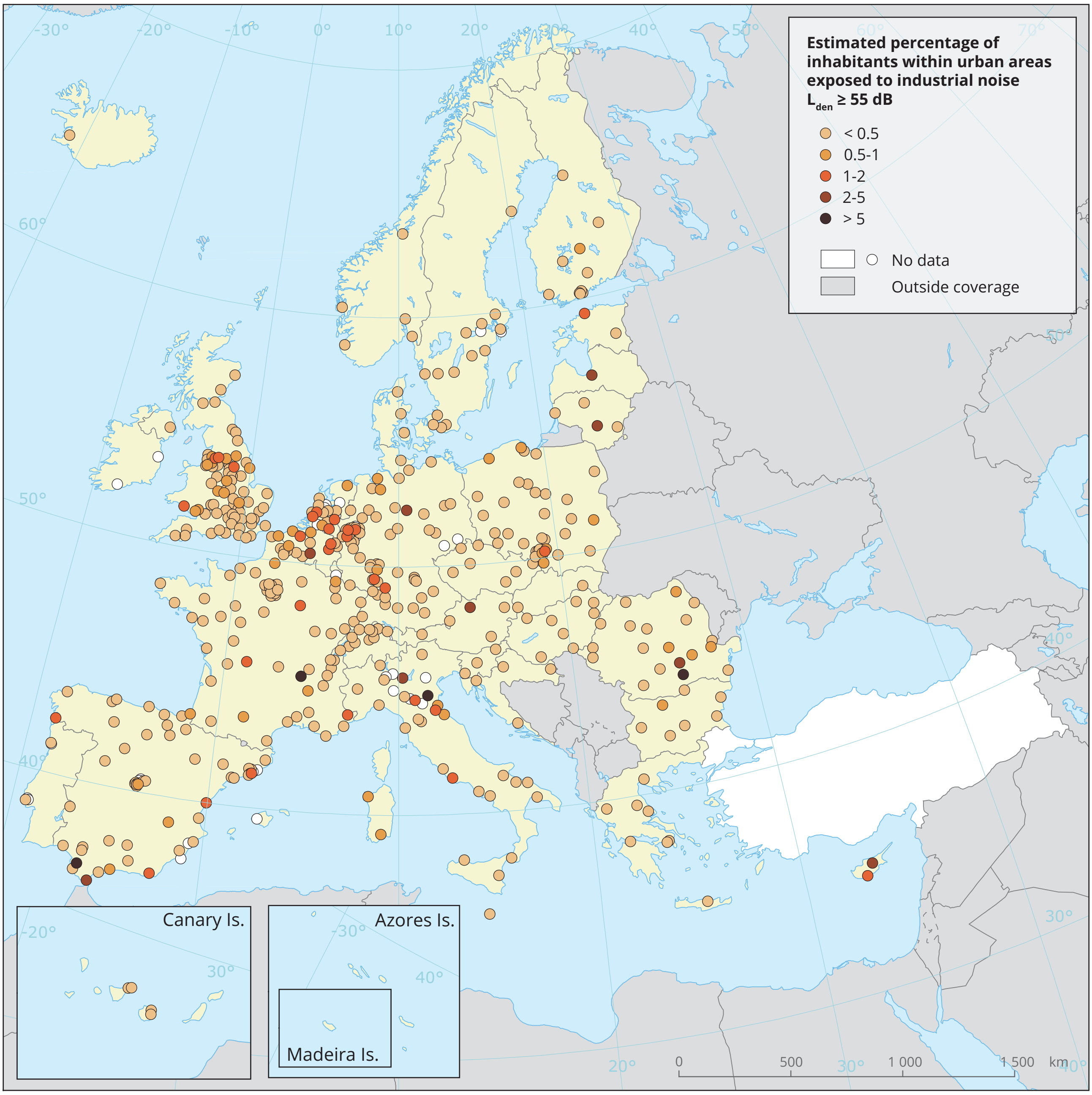
2.6 Past trends and outlooks

Trends between the three reporting rounds of noise mapping (i.e. 2007, 2012 and 2017) are difficult to establish because of comparability issues across the different reporting years. Therefore, past trends should be interpreted with caution (Box 2.3).

Estimated trends between 2012 and 2017 suggest that the number of people exposed to levels of noise considered harmful to human health has generally remained stable across most of the noise sources (Figure 2.16 and Figure 2.17). A significant increase over the years is observed only for railway noise outside urban areas during both the day-evening-night and the night-time periods and for aircraft noise outside urban areas during the night-time period (Table 2.2). However, as these sources are much less prevalent than road traffic noise, the number of additional people affected by these increases is relatively low.

Efforts to reduce exposure to noise from individual sources may be offset by continuing migration to urban areas, which implies a growth in people, activity and traffic. An increased demand for passenger and goods transport across cities, regions and countries

Map 2.7 **Estimated proportion of inhabitants within urban areas exposed to industrial noise L_{den} ≥ 55 dB in 2017**



Note: Liechtenstein does not have agglomerations under the terms of the END.

Source: EEA (2019d) and ETC/ATNI (2019b).

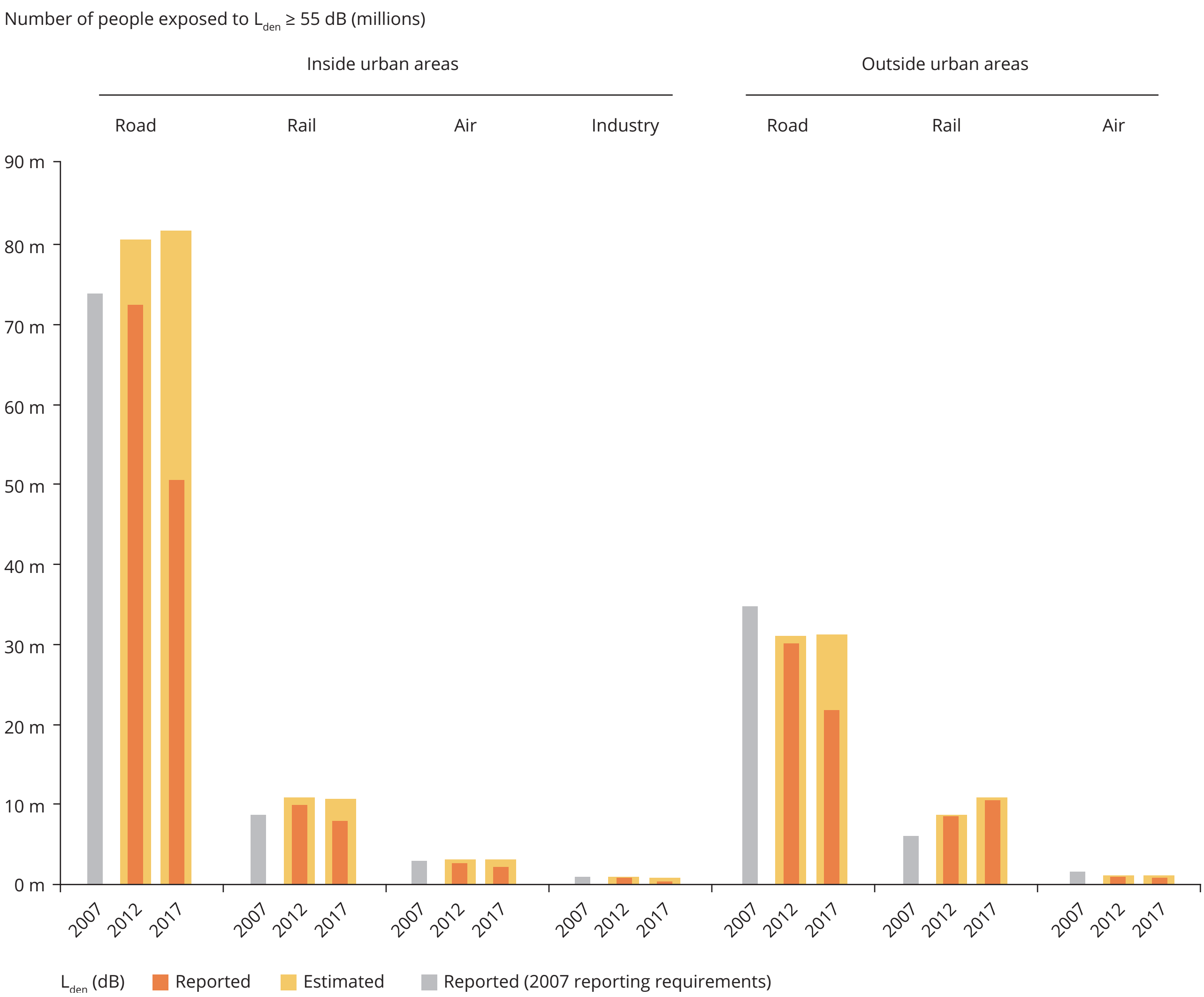
can also negatively influence efforts to reduce the number of people exposed to high noise levels. There are regulations related to noise action plans that have recently come into force but that have not yet clearly generated a reduction in the reported number of people exposed to noise. This is the case, for example, for Regulation 598/2014 on noise management at airports, which calls for cutting noise levels through the deployment of modern aircraft, land use planning, quieter ground-control operations and restrictions on night-time flying (EU, 2014).

Noise outlooks for 2020 and 2030 have been projected using current information on predicted transport and demographic trends and on EU policy objectives related to transport (ETC/ATNI, 2019a). The projections take

Box 2.3 Comparability issues across years

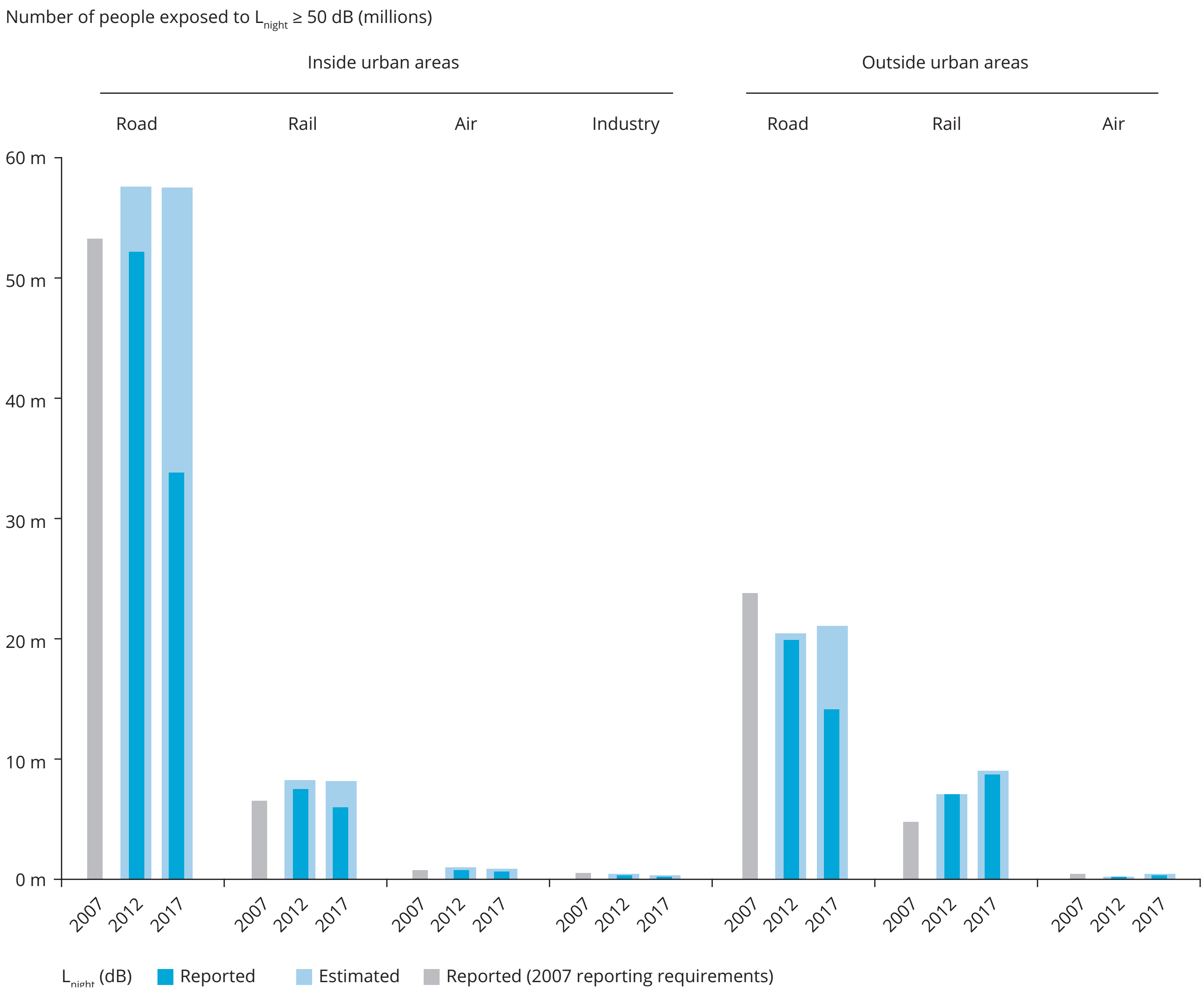
The requirements for reporting data on the 2007 round of noise mapping were different from those for 2012 and 2017. The 2007 data refer to noise in urban areas with more than 250 000 inhabitants, major roads with more than 6 million vehicles per year, major railways with more than 60 000 train passages per year and major airports with more than 50 000 movements per year. However, the data for 2012 and 2017 include urban areas with more than 100 000 inhabitants, major roads with more than 3 million vehicles per year, railways with more than 30 000 train passages per year and major airports with more than 50 000 movements per year (Figure 2.2). There are also comparability problems between the 2012 and 2017 rounds of noise mapping because of a lack of consistency in mapping method approaches as well as incomplete reporting. For instance, the reporting of the 2012 data is approximately 92 % complete, while the 2017 data is approximately 66 % complete.

Figure 2.16 Number of people exposed to L_{den} ≥ 55 dB in areas covered by the END in the three noise reporting rounds in 2007, 2012 and 2017, EEA-33 (Turkey not included)



Sources: EEA (2019d) and ETC/ATNI (2019b).

Figure 2.17 **Number of people exposed to L_{night} ≥ 50 dB in areas covered by the END in the three noise reporting rounds in 2007, 2012 and 2017, EEA-33 (Turkey not included)**



Sources: EEA (2019d) and ETC/ATNI (2019b).

Table 2.2 **Estimated percentage change in population exposure to high levels of noise between 2012 and 2017 in areas covered by the END, EU-28**

	Inside urban areas (% change)				**Outside urban areas (% change)**		
	Road	Rail	Air	Industry	Road	Rail	Air
L_{den} ≥ 55 dB	1.2	-0.4	-0.1	-13.5	0.4	25.9	4.0
L_{night} ≥ 50 dB	-0.1	-1.3	-3.1	-14.5	3.2	27.1	67.0

Source: ETC/ATNI (2019a).

into account the existing population exposure data for the 28 Member States of the EU (EU-28). The main elements that are reflected in the outlook are:

- the projected growth of population, based on the land use based integrated sustainability assessment datasets (JRC, 2014);
- the road and rail traffic growth forecast for passenger and freight transport, based on the EU reference scenario 2016 (EC, 2016a);
- the aviation traffic forecast and technology improvement scenario from the *European aviation environmental report* 2016 (EASA et al., 2016);
- the policy on rail freight silent fleet development under the technical specifications for interoperability relating to the subsystem 'rolling stock — noise' (ERA, 2018);
- the non-binding target of 50 % electrification of the fleet in urban areas (EC, 2011), using an estimated reduction of 0.4 dB.

The outlooks presented here are therefore dependent on the implementation of certain policy objectives as well as to traffic and demographic predictions, which create large uncertainties.

Figure 2.18 and Figure 2.19 show that it is unlikely that noise pollution will decrease significantly by 2020, given that the traffic forecast for road, rail and air transport is projected to increase, as is the number of inhabitants inside urban areas. In the longer term, even if cities were to achieve a 50 % electrification of the fleet (Box 2.4), the number of people exposed to road traffic noise inside urban areas is still set to increase by 2030 by approximately 8 % during the period 2017-2030. If the objective — outlined in the White Paper *Roadmap to a single European transport area: Towards a competitive and resource efficient transport system* (EC, 2011) — of halving the number of conventionally fuelled cars inside urban areas by 2030 is not achieved, a higher increase could be expected.

Noise outside urban areas is estimated to increase by 2030, in particular for road and rail traffic, due to a projected increase in the number of passenger and freight road and rail vehicles. Although railway noise inside and outside urban areas represents a considerable increase in terms of the number of people exposed (i.e. 12 % and 9 %, respectively), this scenario already takes into account the measures to be taken on the retrofitting of silent brakes on freight trains (ERA, 2018).

Aviation noise may stabilise, under the base traffic forecast, only if all the anticipated technology improvements stated in the *European aviation environmental report 2016* (EASA et al., 2016) are met by 2030. If the number of flight movements increases, improvements in aircraft design could only at best stabilise but not significantly reduce overall noise exposure by 2030 (Box 2.5).

The noise contribution from industry inside urban areas is projected to decrease. However, the number of people currently exposed to industrial noise is already estimated to be small, and overall the number of people that will be affected by this reduction is very low.

Box 2.4 Noise from electric vehicles

The future impact of electric vehicles on environmental noise is expected to be significant in urban areas where speeds are low and stationary traffic is common (RIVM, 2010; Campello-Vicente et al., 2017), while on major roads and motorways, where speeds are higher, it is expected to be negligible.

The acoustic benefits of electric vehicles are only evident at low speeds, when the propulsion noise dominates (10-25 km/h), because electric motors are much quieter than their conventionally fuelled counterparts. With increasing speeds, the noise generated by the interaction between the tyres and the road becomes more significant, and it dominates from around 25-30 km/h (Campello-Vicente et al., 2017), meaning that tyre-road noise does not differ systematically between electric and conventionally fuelled cars. For instance, at 50 km/h, the noise reduction potential of an electric car relative to a conventionally fuelled car is only around 1 dB (RIVM, 2010; Campello-Vicente et al., 2017) — a difference barely perceptible to the human ear. On the other hand, the switch to electric scooters in southern European cities where two wheelers are common could reduce noise levels considerably (Fiebig, 2012). However, the potential benefits in terms of exposure to the noise of electric vehicles at low speeds are likely to be impacted by the recent changes in EU Regulation No 540/2014 (EU, 2014), which include a requirement for electric and hybrid vehicles to be fitted with artificial noise. These are intended to compensate for a reduction in audible signals at low speeds (up to 20 km/h), in an effort to help blind and visually impaired pedestrians. Measurements on electric cars show that the introduction of the acoustic vehicle alerting system can increase pass-by levels and compromises the noise benefits of electric cars at speeds below 30 km/h (Laib and Schmidt, 2019).

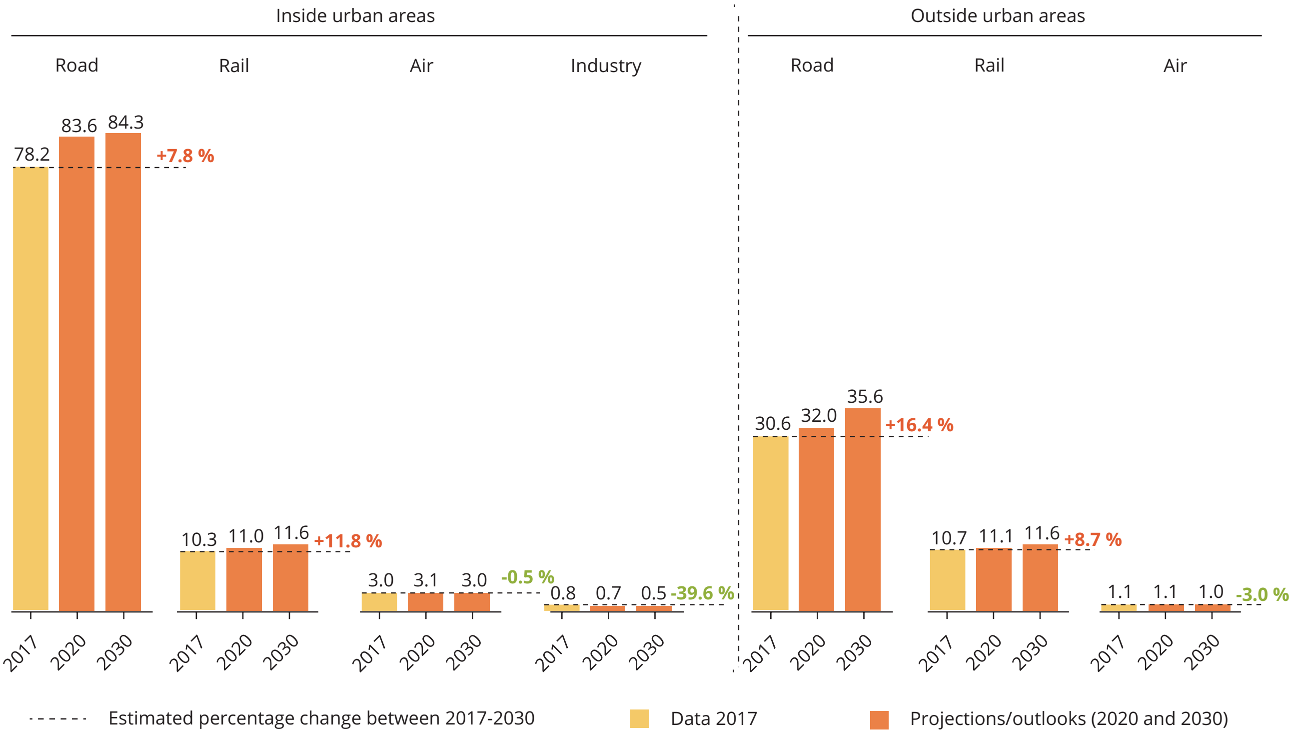
Several studies have explored, by means of models and observational measurements, the impact of changing the fleet in urban areas to electric vehicles. For example, Campello-Vicente et al. (2017) found that, at low speed, e.g. 30 km/h, noise levels were 2 dB higher next to a traffic lane of conventionally fuelled cars than next to the same lane containing only electric vehicles. Other European studies found lower values. The results from the COMPETT project suggest that changing 100 % of the fleet from fuelled passenger cars to electric vehicles would achieve a reduction of 0.6 dB at 30 km/h and about 2.5 dB at 20 km/h (Stahlfest et al., 2015). Another European project found similar values and suggests that a switch to electric cars will have the greatest effect on roads with a small fraction of heavy goods vehicles and a low mean traffic speed (Muirhead, 2015). Lower proportions of electric vehicles in the fleet would also result in a lower overall reduction. In Germany, UBA-DE (2013) estimated that replacing 1 million fuel-powered vehicles with electric vehicles by 2020 (~2 % of the passenger car fleet) would result in a noise reduction of only around 0.1 dB on urban roads at 30 km/h.

Source: Adapted from EEA (2018b).

Image: © Håkan Dahlström/Flickr

Figure 2.18 **Outlooks for 2020 and 2030 in areas covered by the END for the day-evening-night period, EU-28**

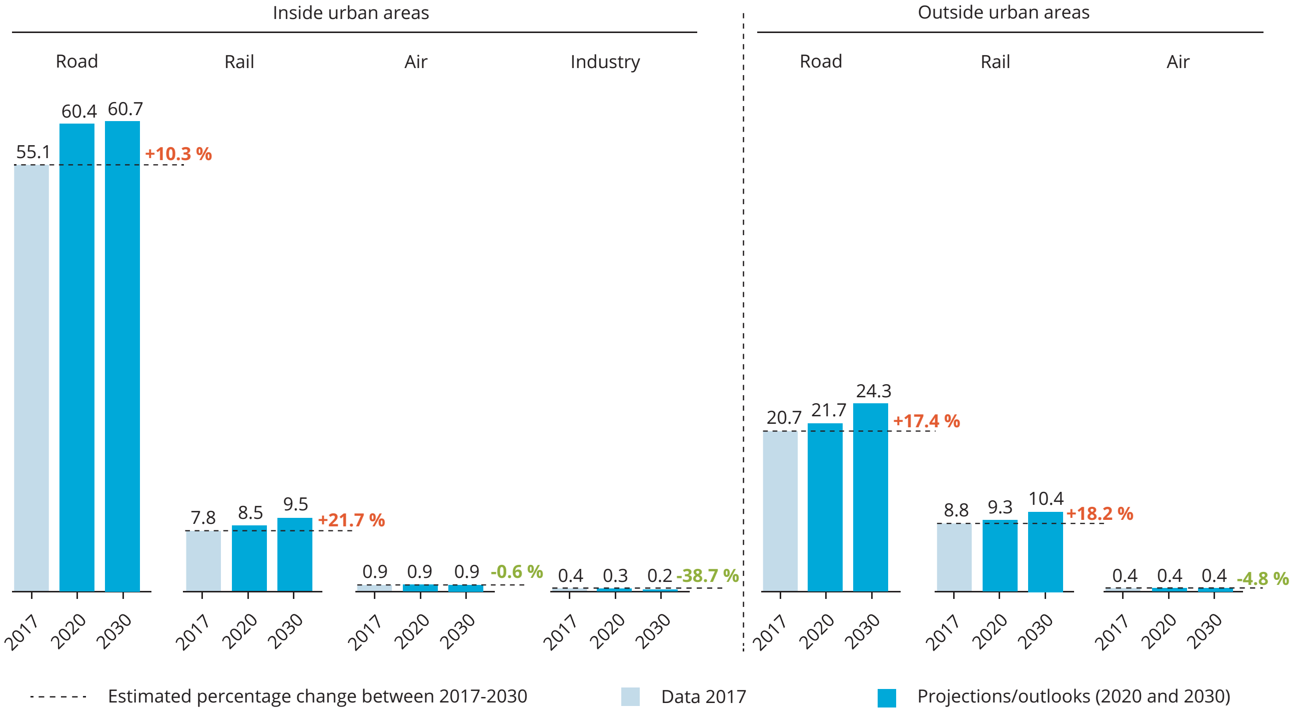
Number of people exposed to L_{den} ≥ 55 dB (millions) and estimated percentage change between 2017-2030



Source: ETC/ATNI (2019a).

Figure 2.19 **Outlooks for 2020 and 2030 in areas covered by the END for the night-time period, EU-28**

Number of people exposed to L_{night} ≥ 50 dB (millions) and estimated percentage change between 2017-2030

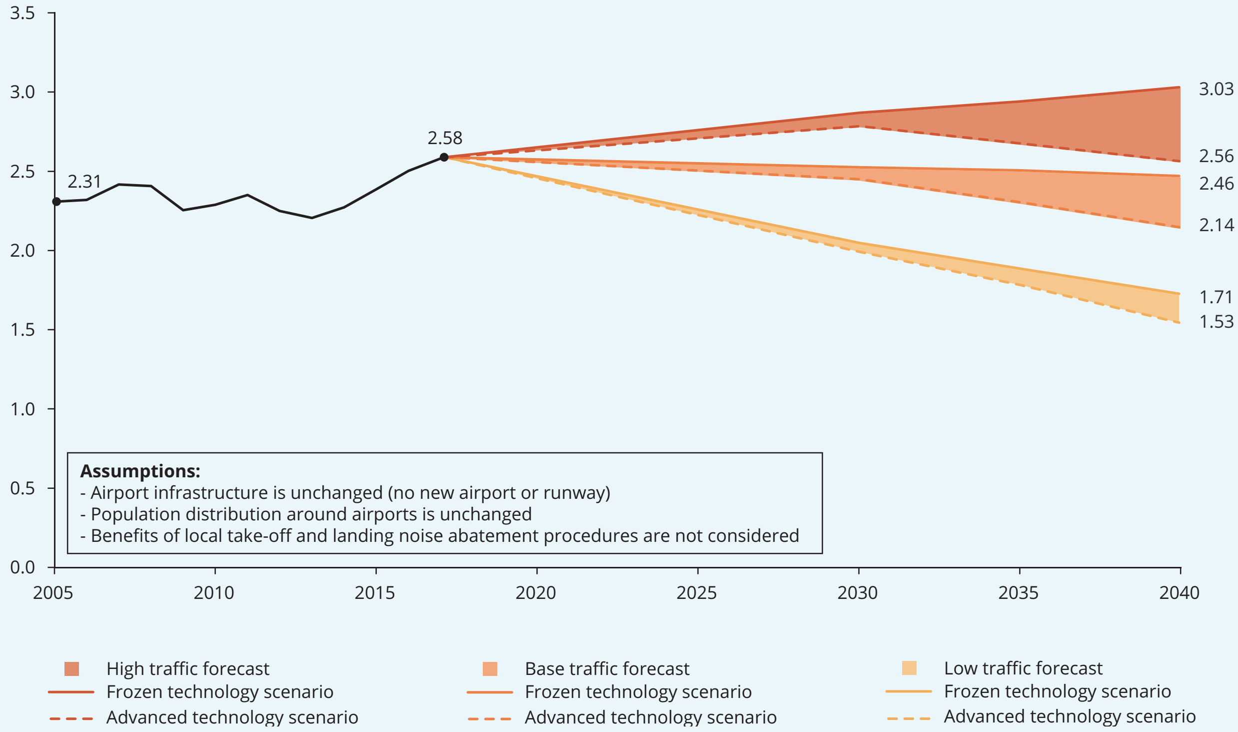


Source: ETC/ATNI (2019a)

Box 2.5 Forecasts for aviation noise — *European aviation environmental report 2019*

There have been significant technological improvements in recent decades that have helped to reduce individual aircraft acoustic emissions. For instance, since 2007, the average noise energy per flight has decreased by 14 %. According to the latest European aviation environmental report, if the latest aircraft types now entering the fleet deliver their expected noise benefits, the total population exposed to noise L_{den} 55 dB and L_{night} 50 dB around major airports could stabilise and even start to decrease by 2030 (see figure below). Achieving such a reduction will depend not only on technology improvements in aircraft but also on air traffic growth.

Total number of people in the L_{den} 55 dB noise contours at 47 major airports (millions)



Source: EASA et al. (2019).

3 Health impacts of exposure to environmental noise

Key messages

- Long-term exposure to environmental noise is estimated to cause 12 000 premature deaths and contribute to 48 000 new cases of ischaemic heart disease per year in the European territory. It is estimated that 22 million people suffer chronic high annoyance and 6.5 million people suffer chronic high sleep disturbance. As a result of aircraft noise, 12 500 schoolchildren are estimated to suffer learning impairment in school.
- Environmental noise (i.e. road, rail, aircraft and industry) features among the top environmental risks to health, with an estimated 1 million healthy years of life lost every year from health effects including annoyance, sleep disturbance and ischaemic heart disease.
- These health impacts are likely to be underestimated, with new World Health Organization evidence demonstrating effects at levels below the obligatory Environmental Noise Directive (END) reporting thresholds. In addition, the END does not comprehensively cover all urban areas, roads, railways and airports across Europe.

3.1 Overview — health effects of environmental noise

Prolonged exposure to environmental noise is one of the major environment related causes of ill health in Europe. Traffic noise, including road, rail and air traffic, has been classified as the second environmental threat to public health in western Europe, behind fine particulate matter (WHO and JRC, 2011; Hänninen et al., 2014). Although the levels of noise generated by transport sources are generally too low to cause biological damage to the ear, it is well established that, if exposure is long term and exceeds certain levels, noise can lead to non-auditory health effects such as annoyance, sleep disturbance, negative effects on the cardiovascular and metabolic system as well as cognitive impairment in children (WHO, 2018). A detailed description of the main health effects of noise is provided in Table 3.1 and Box 3.1.

Subjective responses to noise, such as annoyance or sleep disturbance, depend not only on exposure levels but also on contextual, situational and personal factors. For instance, the impacts may depend on the extent to which noise interferes with what one is trying to do (e.g. sleep, concentrate or communicate) and the expectation of peace and quiet during such activities (Health Canada, 2017). Personal traits, such as an individual's noise sensitivity and attitudes towards the noise source or the emitters (e.g. trust in authorities, perceived fairness, expectations), can also influence annoyance reactions (Guski, 1999; Marquis-Favre et al., 2005; Civil Aviation Authority, 2018).

The most severe effects of noise on health, such as those on the heart and circulatory system that can lead to premature mortality, are hypothesised to be triggered by long-term physiological and emotional stress reactions as well as a reduction in sleep quality (Eriksson and Pershagen, 2018; Basner et al., 2014). These reactions may also affect the metabolic system.

However, in addition to the main health effects described above, noise may have wider impacts on people's health and well-being (Box 3.2).

3.2 WHO Environmental noise guidelines for the European region

Most research to date has focused on the direct cause-effect relationships between transport noise and health outcomes. The strongest base of evidence regarding cause-effect relationships between noise and health has recently been published by the World Health Organization (WHO) Regional Office for Europe in the form of a guidance document *Environmental noise guidelines for the European region* (WHO, 2018).

Table 3.1 Description of the main non-auditory adverse health effects of noise

Annoyance	It is one of the most prevalent responses to noise, and it is described as a stress reaction that encompasses a wide range of negative feelings, including disturbance, dissatisfaction, distress, displeasure, irritation and nuisance. The individual response to noise depends not only on exposure levels but also on contextual, situational and personal factors. It can initiate physiological stress reactions that, if long-term, could trigger the development of cardiovascular disease.
Sleep disturbance	Sleep serves to facilitate vital functions in our body. Noise fragments sleep, reduces sleep continuity and reduces the total amount of sleep time, which can have impacts on alertness, performance at work and quality of life. Sleep restriction causes, among other things, changes in glucose metabolism and appetite regulation, impaired memory consolidation and a dysfunction in blood vessels. Long-term sleep disturbance can also lead to cardiovascular health issues.
Cardiovascular and metabolic effects	Noise is an important risk factor for chronic diseases. Noise exposure activates stress reactions in the body, leading to increases in blood pressure, a changing heart rate and a release of stress hormones. In addition, the cardiovascular and metabolic effects related to noise exposure may also be a consequence of a reduction in sleep quality, caused by noise exposure during the night, among other additional or interrelated mechanisms. These chronic effects can lead to premature mortality.
Cognitive development in children	Noise in classrooms affects children in many ways, including lowering their motivation, reducing speech intelligibility, listening comprehension and concentration, producing annoyance and disturbance, and increasing restlessness. As a result, children exposed to noise at school may experience poorer reading ability, memory and performance. Cognitive impairment could also be linked to noise exposure at home during night-time hours, which can cause low mood, fatigue and impaired task performance the next day. Noise at home may also be linked to hyperactivity and inattention problems, which can cause lower academic performance.

Sources: Adapted from Guski et al. (2017); van Kempen et al. (2018); Clark and Paunovic (2018a); Basner and McGuire (2018); Clark and Paunovic (2018b); Eriksson and Pershagen (2018).

In compiling this guidance, WHO commissioned a set of systematic reviews of evidence encompassing a large amount of previously reported research from all over the world, including large-scale epidemiological studies and socio-acoustic surveys. These analyses and the resulting guidelines focused on key health outcomes that were considered critical, such as cardiovascular disease, annoyance, effects on sleep, cognitive impairment, and hearing impairment and tinnitus. Other non-critical but important health outcomes, such as birth outcomes, quality of life, well-being, mental health and metabolic outcomes, were also captured in the evidence review exercise but were not used to formulate recommendations in the guidelines.

Box 3.1 Noise annoyance, sleep disturbance and their relation to health and well-being

Although noise annoyance and sleep disturbance may be short lived in some situations, in this report and according to the World Health Organization (WHO) environmental noise guidelines (WHO, 2018), noise annoyance and sleep disturbance refer to those affecting people long-term/chronically. In terms of severity, WHO (2018) based its results on the percentage of the population giving the highest ratings for long-term, self-reported noise annoyance and sleep disturbance, namely the 'percentage of the population highly annoyed' and the 'percentage of the population highly sleep disturbed'. Therefore, throughout this assessment, we refer to 'high annoyance' and 'high sleep disturbance' to describe the long-term impacts of noise on annoyance and sleep disturbance.

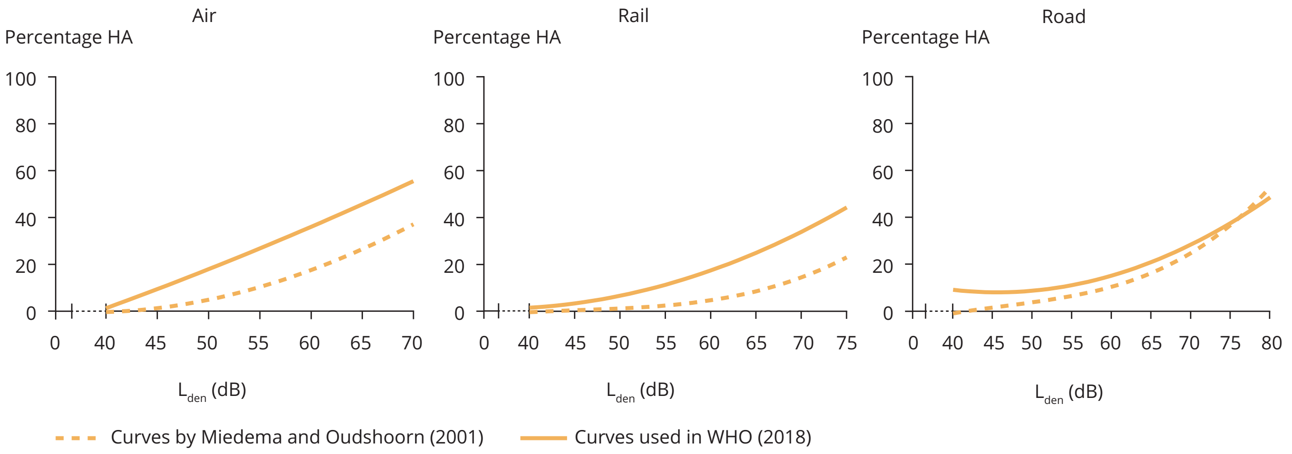
The WHO environmental noise guidelines (WHO, 2018) consider long-term annoyance and sleep disturbance due to noise to be important health outcomes. According to the WHO definition of health, which is 'a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity (International Health Conference, 2002)', documenting only physical health does not present a complete picture of general health. Therefore, being undisturbed by noise in all activities, including sleep, constitutes an asset worthy of protection (WHO, 2018). The importance of considering both annoyance and self-reported sleep disturbance as health outcomes is further supported by evidence indicating that they may play a part in the causal pathway of noise-induced cardiovascular and metabolic diseases (Eriksson and Pershagen, 2018; WHO, 2018).

Table 3.2 **Recommendations from the WHO environmental noise guidelines**

	Reducing noise below these levels is strongly recommended		
Noise indicator	Road	Rail	Air
L_{den}	53 dB	54 dB	45 dB
L_{night}	45 dB	44 dB	40 dB

Source: WHO (2018).

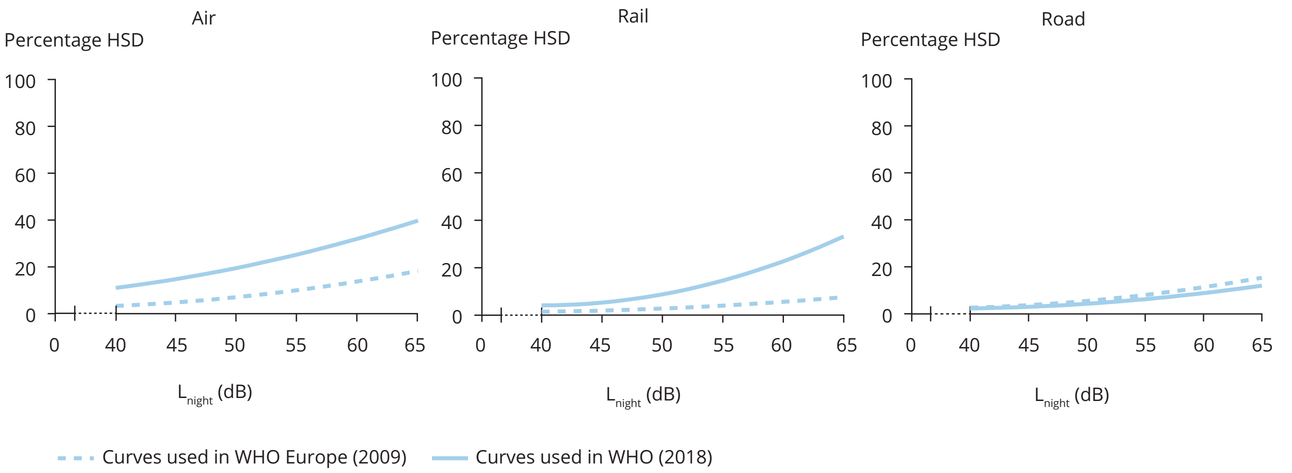
Figure 3.1 **Estimated percentage of people in the category 'Highly Annoyed (HA) by noise for air, road and rail traffic' according to the WHO environmental noise guidelines**



Note: Dashed lines show the previous curves used by the EU from Miedema and Oudshoorn (2001).

Source: Guski et al. (2017).

Figure 3.2 **Estimated percentage of people in the category 'Highly Sleep Disturbed (HSD) by noise for air, road and rail traffic' from the WHO environmental noise guidelines**



Note: Dashed lines show previous curves from *Night-Noise Guidelines for Europe* (WHO Europe, 2009).

Source: Basner and McGuire (2018).

Table 3.3 Recommended health outcomes for noise health impact assessments (HIAs) for road, rail and air traffic

Source	Outcomes that can be quantified in a HIA	Outcomes that can be potentially quantified in a HIA
Road	• Incidence of ischaemic heart disease • Annoyance • Sleep disturbance	• Incidence of stroke • Incidence of diabetes
Rail	• Annoyance • Sleep disturbance	
Air	• Annoyance • Sleep disturbance • Reading and oral comprehension in children	• Incidence of ischaemic heart disease • Change in waist circumference

Source: WHO (2018).

The main recommendations from the guidelines are presented in Table 3.2. These recommendations define an exposure level above which a relevant increase in negative effects occur, expressed in terms of L_{den} and L_{night}, which relate to outdoor noise as an annual average. The recommendations for all sources of traffic noise were considered to be 'strong', meaning that the recommendation can be adopted as policy in most situations. These guideline values are based on the confidence that reducing noise to the stated levels will outweigh the potential adverse consequences. However, the guidelines do not include recommendations for locations exposed to noise from a combination of sources or for vulnerable groups.

An important finding from the review of evidence commissioned by the WHO suggests that annoyance and sleep disturbance due to noise from rail and air sources have increased in recent years. Therefore, exposure-response relationships based on older noise annoyance or sleep disturbance data for these sources may no longer apply. Figure 3.1 and Figure 3.2 show the change in annoyance and sleep disturbance between the so-called 'EU standard curves' (EEA, 2010) and the new relationships provided by the WHO (2018). The causes of the changing exposure-response relationships between aircraft and rail noise and annoyance and sleep disturbance are still unclear.

As a result of the scientific evidence reviewed, the guidelines recommend a set of health outcomes that can be quantified in a noise health impact assessment (HIA) (Table 3.3). Some other health outcomes can also be potentially included in a health risk assessment, although these relationships need further confirmation

Box 3.2 Other health effects of noise

Although current guidance from the WHO mainly focuses on direct links between noise levels and priority health effects such as annoyance, sleep disturbance, cognition impairment, cardiovascular outcomes and hearing impairment, given the disease-inducing mechanisms of noise, i.e. stress and the disturbance of night-time sleep, noise may have wider impacts on people's health and well-being.

For example, it has recently been suggested that exposure to transport noise may be involved in the development of some types of breast cancer (Sørensen et al., 2014; Hegewald et al., 2017; Andersen et al., 2018). It is also hypothesised that psychological stress caused by noise may exacerbate respiratory disease (Recio et al., 2016). Noise causes stress and annoyance and has also been linked to serious mental health problems such as depression and anxiety (Beutel et al., 2016; Orban, et al., 2016).

Other studies have shown the indirect impacts of living in noisy areas. For instance, transport noise may, through sleep disturbance, lead to physical inactivity (Foraster et al., 2016; Roswall et al., 2017). Other associations between traffic noise and lifestyle factors such as smoking, alcohol consumption or medication intake have also been reported (Bocquier et al., 2014; Roswall et al., 2018).

from more studies of higher quality. The recommended health endpoints that can be quantified all belong to the priority measures classified as critical by the guidelines development group.

3.3 Methodology used to assess health impacts

In this assessment, only those health endpoints that have demonstrated a reasonable causal relationship between noise exposure and adverse human health effects and that are recommended to be used in a HIA by the WHO (2018) have been used (Table 3.3). Thus, the associations that have been reported between noise exposure from road, rail and air traffic and high annoyance, high sleep disturbance and the incidence of ischaemic heart disease (IHD) were selected for this assessment. Furthermore, premature mortality due to IHD was included following the recommendation of van Kamp (2018). In addition to the effects of these relationships on adults, the effects of aircraft noise on reading comprehension in children were also included. The health impacts were calculated using the number of people exposed to levels of noise starting at 55 dB L_{den} and 50 dB L_{night}, as reported under the Environmental Noise Directive (END).

Table 3.4 summarises the relationships between noise and the health effects that were used in this assessment. Although the WHO review found limited evidence between cardiovascular effects and noise from rail or air sources and the guidelines do not make a recommendation to include these health endpoints in a HIA, in this assessment, it is assumed that the cardiovascular effects of road traffic noise can be extrapolated to aircraft and railway noise, given that the biological mechanisms involved are thought to be similar for the different sources (van Kamp, 2018). In the case of industrial noise, which was outside the scope of the WHO guidelines, we used relationships from older studies that refer to industrial noise as well as relationships from other sources of noise, depending on the health outcome. The WHO guidelines do not provide a relationship between aircraft noise and cognitive impairment in children. Therefore, the results of the RANCH study on reading comprehension were also re-analysed to derive an exposure-response relationship for reading impairment.

The *Environmental noise guidelines for the European region* (WHO, 2018) have introduced new relationships and new recommendations that differ from the ones used in past assessments, such as *Noise in Europe* 2014 (EEA, 2014b). The main changes between this and previous Health Impact Assessments (HIAs) are the use of updated relationships for annoyance and sleep disturbance; the use of updated relative risk ratios and starting levels for ischaemic heart disease incidence and mortality; and the exclusion of hypertension and stroke from the assessment.

The completeness of the data reported for the 2017 round of noise mapping is about 66 %. Therefore, gap-filled data were used to estimate the total area covered by the END. The health impact depends on the 'base-line' prevalence (frequency) or incidence (new cases per year) of health effects. These differ between countries and were taken into account in the calculations. The calculations in this assessment include a non-uniform distribution across noise bands, which was estimated using a 1-dB resolution for calculating the average exposure in each band. The methods employed for this HIA are described in more detail in ETC/ACM (2018).

The resulting number of people estimated to be affected by each environmental health outcome is also used in this assessment to estimate the burden of disease due to environmental noise in the disability-adjusted life-years (DALYs).

3.4 Health impact assessment

The impacts of noise pollution in Europe are highly significant. It is estimated that around 22 million adults living in agglomerations or near major noise sources with levels starting at 55 dB L_{den} are highly annoyed by noise from road traffic, railways, aircraft and industry. Moreover, it is estimated that 6.5 million adults suffer severe sleep disturbance because of night-time noise levels equal to or above 50 dB L_{night}. The exposure to environmental noise from road traffic, railways, aircraft and industry is estimated to contribute every year to about 48 000 new cases of ischaemic heart disease and 12 000 premature deaths. Aircraft noise has also been associated with a decrease in children's cognitive performance in schools that are affected by flight paths. As a result, it is estimated that around

Table 3.4 Relationships between noise and the health effects used in this assessment

Health effect	Population	Source	Relationship
High annoyance	Adults	Road	Guski et al. (2017) $(78.927 - 3.1162 \times L_{den} + 0.0342 \times L_{den}^2)/100$
		Rail	Guski et al. (2017) $(38.1596 - 2.05538 \times L_{den} + 0.0285 \times L_{den}^2)/100$
		Air	Guski et al. (2017) $(-50.9693 + 1.0168 \times L_{den} + 0.0072 \times L_{den}^2)/100$
		Industry	Miedema and Vos (2004) $1\text{-normal}((72 - (-126.52 + (L_{den}) \times (2.49)))/\text{sqrt}(2054.43))$
High sleep disturbance	Adults	Road	Basner and McGuire (2018) $(19.4312 - 0.9336 \times L_{night} + 0.0126 \times L_{night}^2)/100$
		Rail	Basner and McGuire (2018) $(67.5406 - 3.1852 \times L_{night} + 0.0391 \times L_{night}^2)/100$
		Air	Basner and McGuire (2018) $(16.7885 - 0.9293 \times L_{night} + 0.0198 \times L_{night}^2)/100$
		Industry	Miedema and Vos (2007) $1\text{-normal}((72 - (-90.70 + (L_{night}) \times (1.80)))/\text{sqrt}(1\,789 + 272))$
Reading comprehension	Children	Air	*Clark et al. (2006) and van Kempen (2008)* $1/(1 + \exp(-(\ln(0.1/0.9) + (\ln(1.38)/10 \times (L_{den} - 50))))$ if $L_{den} \geq 50$ dB and 0.1 if $L_{den} < 50$ dB
Ischaemic heart disease incidence	Adults	Road, rail, air, industry	van Kempen et al. (2018) relative risk (RR) derived from road noise $RR = \exp(\ln(1.08)/10 \times (L_{den} - 53))$ if $L_{den} \geq 53$ dB, and RR = 1 if $L_{den} < 53$ dB
Premature mortality due to ischaemic heart disease	Adults	Road, rail, air, industry	van Kempen et al. (2018) RR derived from road noise $RR = \exp(\ln(1.05)/10 \times (L_{den} - 53))$ if $L_{den} \geq 53$ dB, and RR = 1 if $L_{den} < 53$ dB

Note: Sqrt, square root (√).

Source: (ETC/ACM, 2018)

12 500 children in Europe between the ages of 7 and 17 years have a reading impairment due to exposure to aircraft noise. A breakdown by source and area is shown in Table 3.5.

Instead of just assessing the number of premature deaths, the WHO developed methods to quantify the burden of disease from environmental noise using DALYs, which combine years of life lost due to premature mortality and years of life lost due to time lived in states of less than full health (WHO and JRC, 2011). This methodology was used to calculate the burden of disease as a result of annoyance, sleep disturbance and reading impairment, using exposure-response relationships as well as the population-attributable fraction for IHD. The disability weight factors (DWs) reported in WHO (2018) were used in the calculation.

Table 3.6 shows the burden of disease results estimated from the noise data covered by the END. DALYs lost due to noise-induced health outcomes were estimated to be equivalent to 437 000 years for sleep disturbance, 453 000 years for annoyance, 156 000 years for heart disease and 75 years for cognitive impairment of children. Although a simple summation of DALYs for each health effect may lead to some double counting, the results tentatively

Table 3.5 Estimated number of people suffering from various health outcomes due to environmental noise in 2017, EEA-33 (Turkey not included)

		High annoyance	High sleep disturbance	Ischaemic heart disease	Premature mortality ([a])	Cognitive impairment in children
Inside urban areas	Road	12 525 000	3 242 400	29 500	7 600	
	Rail	1 694 700	795 500	3 100	800	
	Air	848 300	168 500	700	200	9 500
	Industry	87 200	23 400	200	50	
Outside urban areas	Road	4 625 500	1 201 000	10 900	2 500	
	Rail	1 802 400	962 900	3 400	900	
	Air	285 400	82 900	200	50	2 900
	Total ([b])	**21 868 500**	**6 476 600**	**48 000**	**12 100**	**12 400**

Notes: ([a]) Refers to mortality due to ischaemic heart disease.

([b]) There may be double counting for annoyance and sleep disturbance because of the combined effects of multiple sources. It is estimated to be no more than 13 % for annoyance and 16 % for sleep disturbance. Double counting for ischaemic heart disease and mortality is estimated to be negligible (ETC/ACM, 2018)

indicate that about 1 million healthy years of life are lost every year as a result of environmental noise for the health effects assessed. In terms of individual noise sources, road traffic noise — as the most prevalent source of environmental noise — not surprisingly has the largest contribution to the burden of disease due to noise (75 %), followed by railway (20 %), aircraft (4 %) and industry (0.5 %) noise. The major part of the burden of disease including annoyance, sleep disturbance, heart disease and cognitive impairment due to noise, occurs inside urban areas of more than 100 000 inhabitants. However, as shown in Table 3.6, it should be noted that there are different approaches to estimating the burden of disease due to noise, in terms of health outcomes included.

However, the effects presented here may be underestimated, as new scientific evidence shows that health and well-being can be affected by noise levels lower than those specified under the END (Table 3.2). Currently, there is a lack of data on the number of people exposed below 55 dB L_{den} and 50 dB L_{night}, as the reporting of such levels by countries is voluntary. Therefore, the health impact of noise is likely to be greater than that presented in this assessment. Moreover, the END data do not cover a country's full territory, and therefore there may be people affected by noise that are not accounted for in the estimations presented (Box 3.3).

The associated decline in the population's health because of noise has an economic impact in Europe. There are different approaches for quantifying the economic costs of noise on health, one of which relies on assigning a monetary cost per DALY (Defra, 2014.) Although the assessment of the costs in terms of DALYs may differ from country to country, if we assume that the monetary cost per DALY is EUR 78 500 (VITO, 2003), the resulting economic impact of noise is estimated to be EUR 35 billion for annoyance, EUR 34 billion for sleep disturbance, EUR 12 billion for IHD and EUR 5 million for cognitive impairment in children. Monetary costs can also exist as a result of reduced house prices, loss of labour days and reduced possibilities for land use (EC, 2000).

Table 3.6 Estimation of the burden of disease (BoD) due to environmental noise for sources covered by the END, EEA-33 (Turkey not included)

Health effect	Public health impact (DALYs/year) and (DALYs/year) per million ([a])	Health effects included in different approaches to estimating noise BoD		
		WHO and JRC (2011)	Hänninen et al. (2014)	IHME (2018)
High annoyance ([b])	453 000 900 per million people	✓	x	x
High sleep disturbance ([b])	437 000 800 per million people	✓	✓	x
Ischaemic heart disease ([c])	156 000 300 per million people	✓	✓	✓
Cognitive impairment in children ([d])	75 ~0	✓	x	x

Notes: ([a]) The DWs used for the calculation of DALYs are those indicated in WHO (2018). Other sources of information suggest using smaller DWs for annoyance, sleep disturbance and reading impairment (van Kamp, 2018).

([b]) There may be double counting because of the combined effects of multiple sources. It is estimated to be no more than 13 % for annoyance and 16 % for sleep disturbance (ETC/ACM, 2018).

([c]) Includes incidence and mortality.

([d]) Impairment is calculated only for aircraft noise.

Box 3.3 Expanding the coverage of the END to calculate health effects due to environmental noise — Switzerland

Areas outside major agglomerations, major roads, major railways and major airports are not included in the Environmental Noise Directive (END), meaning that the health impacts of noise are likely to be greater than those estimated using the END data submitted by countries. Moreover, underestimations also exist because mandatory reporting only starts at 55 dB L_{den} and 50 dB L_{night}, levels above those at which harmful effects on health start to occur.

Switzerland has conducted a study on the effects of traffic noise on health, expanding the END coverage to all roads, railways and airports in the country (i.e. the END only requires countries to model major roads, railways and airports). In addition to this, the number of people exposed to levels starting at 40 dB was used to calculate the impact of noise on health, meaning that people exposed to levels below the END reporting thresholds were included in the HIA. The table below shows the extent of the underestimation of the health impact of road noise when using the END requirements. As it can be seen, a HIA using the number of people exposed to all road sources as well as noise levels below the END reporting thresholds may result in an underestimation of about 60 % for annoyance and sleep disturbance and about 70 % for ischaemic heart disease.

Number of people exposed to:	L_{den}		L_{night}	
	40-54.9	≥ 55	40-49.9	≥ 50
All roads in Switzerland ([a])	3 734 805	4 406 318	3 794 963	3 036 686
Roads reported under the END ([b])	Unknown	3 003 300	Unknown	2 093 000

DALYs due to:	High annoyance	High sleep disturbance	Incidence and mortality due to ischaemic heart disease
All roads in Switzerland ([a])	22 116	22 254	8 947
Roads reported under the END ([b])	8 916	8 237	2 367

Note: ([a]) Assessed for all roads in Switzerland with levels starting at 40 dB L_{den} and L_{night}.

([b]) Assessed using major roads of more than 3 000 000 passages a year and roads inside agglomerations for levels starting at 55 dB L_{den} and 50 dB L_{night}.

Source: Ecoplan (2019).

4 Social inequalities and vulnerability to environmental noise

Key messages

- Exposure to environmental noise does not affect everyone equally. Socially deprived groups as well as groups with increased susceptibility to noise may suffer more pronounced health-related impacts of noise.
- While there is some evidence of links between lower socio-economic status and exposure to noise, there are also studies that did not find any relationship. This highlights that a relationship is very much dependent on the type of socio-economic indicator, the type of noise indicator and the spatial scale used, as well as local characteristics of the area.
- Analyses at highly resolved spatial scales are needed for a better understanding of the social distribution of environmental noise exposure.

4.1 Exposure to environmental noise and social inequalities

Exposure to environmental noise does not affect everyone in the same way. Personal characteristics, including age, gender, lifestyle or pre-existing health conditions, determine how susceptible people are to adverse health effects due to noise pollution. In addition, people's ability to avoid or cope with noise is influenced by their socio-economic status. For example, socio-economically advantaged people may have the resources to afford housing in tranquil areas. Most likely, a combination of higher exposure, increased vulnerability and fewer resources may result in more pronounced noise-related health impacts among socially disadvantaged people (EC, 2016c).

In terms of assessing the social inequalities in environmental noise exposure in Europe, three main pieces of work were recently published. These include an EEA pan-European assessment of the link between socio-economic determinants and road noise data submitted under the Environmental Noise Directive (END) (EEA, 2018c), an assessment carried out by the World Health Organization (WHO) Regional Office for Europe of the link between socio-economic indicators and noise complaints from neighbours or the street (WHO, 2019), and a systematic review done within the same context of the aforementioned assessment by the WHO Regional Office for Europe (Dreger et al., 2019). Table 4.1 summarises the findings of each study.

Overall, as shown in Table 4.1, although the existing studies are very heterogeneous, there are inequalities in environmental noise exposure. However, the results seem to depend highly on the socio-economic indicator, the noise indicator and the spatial area used, with further research needed in this area.

Dreger et al. (2019) suggest that indicators representing material aspects associated with where people can afford to live — such as income, deprived living area, mean value of a dwelling or ownership of a dwelling — are somehow linked to higher noise exposure in people with a lower socio-economic

Table 4.1 Summary of the main findings of recent pan-European studies on social inequalities in environmental noise exposure

EEA (2018c)	Title	*Unequal exposure and unequal impacts: Social vulnerability to air pollution, noise and extreme temperatures in Europe*
	Study description	An exploratory pan-European assessment of vulnerable groups' exposure to road traffic noise. The relationships between the proportion of people exposed to road traffic noise, submitted by countries under the END, and various socio-economic indicators were investigated using large spatial scales (e.g. Nomenclature of Territorial Units for Statistics (NUTS) 3, NUTS 2 and Urban Audit cities).
	Main findings	Associations between population exposure to noise and indicators of deprivation or vulnerability were found to be relatively weak. Weak but significant associations were found for unemployment in Urban Audit cities and household income deprivation at the NUTS 2 level (Figure 4.1). This may suggest that cities and regions containing poorer populations are also more exposed to noise. The results have a large degree of uncertainty because of limited data availability.
WHO (2019)	Title	*Environmental health inequalities in Europe. Second assessment report*
	Study description	A systematic analysis of data from the Eurostat EU-SILC (European Union Statistics on Income and Living Conditions) survey from the period 2007-2016 on self-reported noise annoyance in terms of complaints about noise from neighbours or the street. The analysis was conducted for countries, cities and rural areas.
	Main findings	Inequalities in complaints about noise from neighbours or the street were found among different income levels: poorer people showed a higher prevalence, especially in Euro 1 countries ([a]). The same pattern of inequalities in self-reported noise annoyance can be observed for urban and rural regions in Euro 2 countries ([b]). Trends from 2007 to 2016 show that absolute inequalities have increased, especially in Euro 1 countries.
Dreger et al. (2019)	Title	*Social inequalities in environmental noise exposure: A review of evidence in the WHO European region*
	Study description	A systematic review that examined social inequalities in environmental noise exposure in the WHO European region. The review included eight studies and was conducted in the context of a WHO project to update the 2012 assessment report on environmental health inequalities in the WHO European region.
	Main findings	The results were mixed between and within different indicators of socio-economic position (SEP). Studies using indicators of material deprivation and studies using deprivation indices pointed towards higher environmental noise exposure in lower SEP groups. None of the studies found results pointing towards higher exposure in socially advantaged groups exclusively.

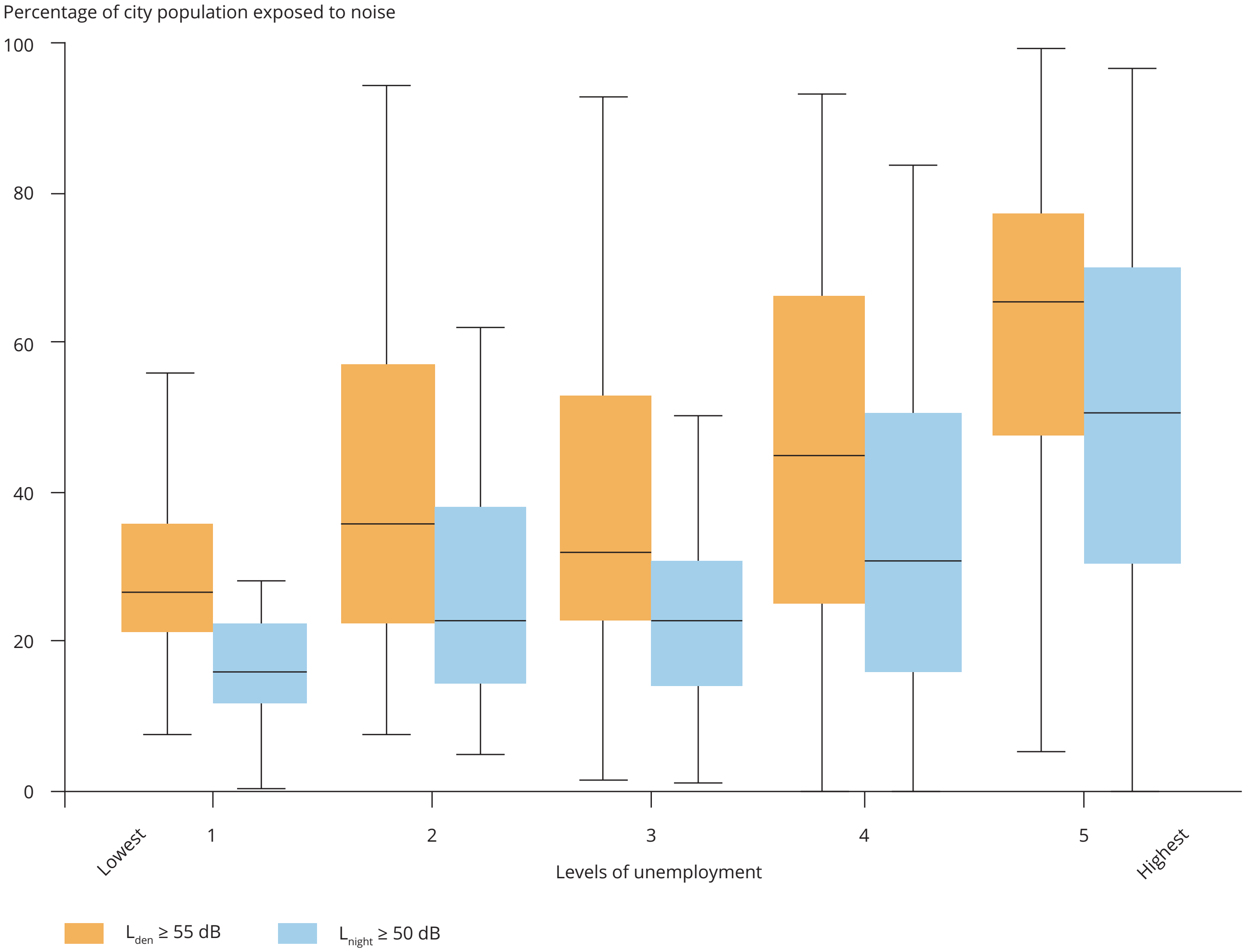
Notes: ([a]) Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Norway, Sweden, Switzerland, United Kingdom.

([b]) Bulgaria, Croatia, Cyprus, Czechia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia.

position (SEP). For instance, a poor-quality environment can lower local house prices, making properties more affordable and therefore attractive to people with lower incomes. There is evidence that house values are reduced in noisy areas. In particular, aircraft noise may negatively affect house prices even more than road traffic noise (Kopsch, 2016; Trojanek et al., 2017). However, house prices are context dependent, and the noise level does not always constitute a significant variable. Some recent individual studies also suggest that ethnic minorities tend to be exposed to higher levels of environmental noise (Casey et al., 2017; Tonne et al., 2018).

When assessing inequalities due to noise at the European level, poverty level and income have been shown to be related to higher perceived noise levels. However, an EEA assessment looking at the relationships between the number of people exposed to high noise levels and socio-economic indicators

Figure 4.1 Differences in the proportion of the population exposed to high levels of noise among European cities classified according to unemployment levels



Notes: The data are based on reported values submitted under the END for the 2012 phase of noise mapping up until 15 April 2017. The levels of unemployment represent quintiles (i.e. classes containing 20 % of the cities, ranked according to values), with 1 representing the lowest vulnerability and 5 the highest.

Source: EEA (2018c)

found only weak associations for unemployment and household income level. To better understand the social distribution of environmental noise exposure, all studies call for improved data in terms of socio-economic data and noise data at small spatial scales. This may be particularly relevant for road traffic noise, in which large variations in noise exposure can occur within a relatively small geographical area because of the shielding effect of buildings.

4.2 Vulnerability to noise

Environmental health inequalities may arise not only as a result of exposure differentials. The health impacts of noise also depend on individual susceptibility and the ability to recover from such impacts. Although most research has concentrated on the impacts of noise on children, there are other groups that could be disproportionately affected by noise. A summary of the groups vulnerable to environmental noise is described in Table 4.2. The WHO (2018) recognises that there is a lack of literature on the effects of noise on vulnerable people and that there is a need for future research to focus on vulnerable groups.

Currently, there is a limited number of policy measures that limit vulnerable groups' exposure to noise — existing measures mainly focus on children. The most relevant recommendations have been made by the WHO. The WHO guidelines for community noise (Berglund et al., 1999) recommend that noise levels in school playgrounds

Table 4.2 Environmental noise impacts on vulnerable groups

Group	Vulnerability	Adapted from
Children	Exposure to aircraft noise in schools affects children's cognition. Compared with adults, children are in an important learning and developmental phase and may therefore be disproportionately affected by noise. Children also may lack coping strategies and have less control over environmental noise than adults. As children also spend more time in bed, they may be exposed more to night noise levels.	WHO Europe, 2009; Clark and Paunovic, 2018a
Elderly	Since sleep structure becomes more fragmented with age; elderly people are more vulnerable to sleep disturbance. Elderly people may also be more prone to suffering cardiovascular effects due to noise than younger adults. The risk of suffering health conditions related to the heart and circulatory system increases with age. In addition, the elderly typically spend more time at home or have lived in a property exposed to noise for many years.	WHO Europe, 2009; Tobias et al., 2014; Halonen et al., 2015
Shift workers	Shift workers may be at an increased risk of experiencing negative impacts from exposure to environmental noise, because their sleep structure is under stress. Shift workers may also need to sleep during the day, when environmental noise levels are higher.	WHO Europe, 2009
Pre-existing health conditions	People suffering from chronic diseases may have a higher cardiovascular risk due to noise than those without such pre-existing conditions.	Babisch, 2006
Noise sensitive	People considered to be noise sensitive (e.g. people who pay more attention to noises, discriminate more between noises, find noises more threatening and out of their control, and react to and adapt to noises slowly) are generally more susceptible to sleep disturbance as well as psychological effects due to noise.	Stansfeld, 1992; Marks and Griefahn, 2007
Pregnant women	The sleep structure of pregnant women becomes more fragmented. Environmental noise may also increase the risk for pre-term birth and low birth weight.	WHO Europe, 2009; Nieuwenhuijsen et al., 2017
Socio-economically disadvantaged	Lower socio-economic groups may be exposed to higher levels of noise. Those living in more deprived locations have less access to quiet areas. Deprived populations may experience the worst effects of noise pollution as a result of poorer housing, pre-existing health conditions or fewer opportunities for coping with noise.	EEA, 2018c; Dreger et al., 2019; WHO, 2019

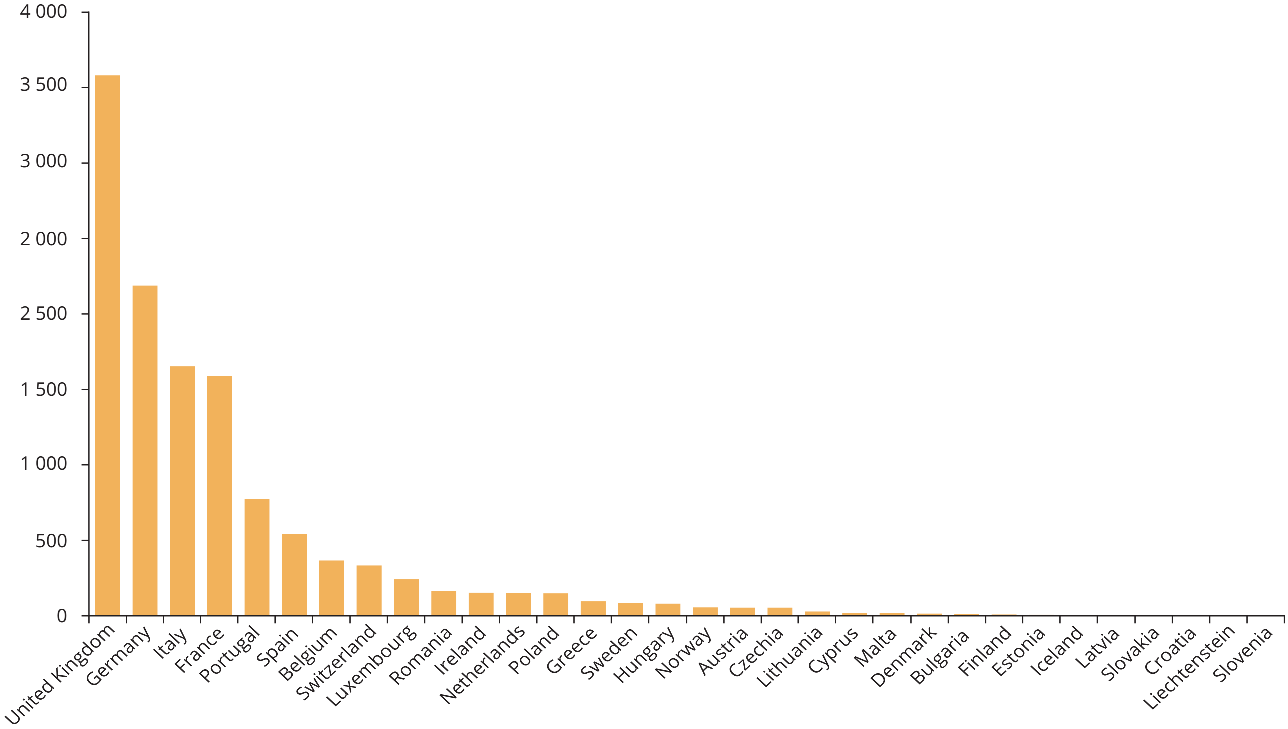
should not exceed 55 dB(A), while indoor classroom noise levels should not exceed 35 dB(A). The recently published WHO environmental noise guidelines (2018) include exposure levels above which cognitive effects on children are observed. Based on the evidence review underpinning the guidelines, a risk of impaired reading and comprehension in children increases at outdoor levels of 55 dB L_{den} in school settings.

However, the END does not set any reporting activities that target specific environments used by vulnerable groups of people. Annex IV on minimum requirements for strategic noise mapping states that a strategic noise map may be presented as the estimated number of dwellings, schools and hospitals in a certain area that are exposed to specific values of a noise indicator. However, according to Annex VI of the END, it is not necessary to send this information to the European Commission. In addition, Annex III of the END states that 'if necessary, specific dose-effect relations could be presented for vulnerable groups of the population'. However, it does not specify who should be treated as vulnerable and when it would be necessary to consider these groups.

Nonetheless, from the data collected under the END, the number of children potentially suffering from reading impairment can be estimated. The number of children aged between 7 and 17 years in 2017 suffering from reading impairment due to aircraft noise is shown in Figure 4.2. The proportion of children per country is shown in Figure 4.3. The data show that the estimated number of schoolchildren with reading impairment due to aircraft noise depends on the size of the country and the number of airports. The proportion of children potentially affected by reading impairment in the areas exposed to aircraft noise ranges approximately between 2 % and 7 %.

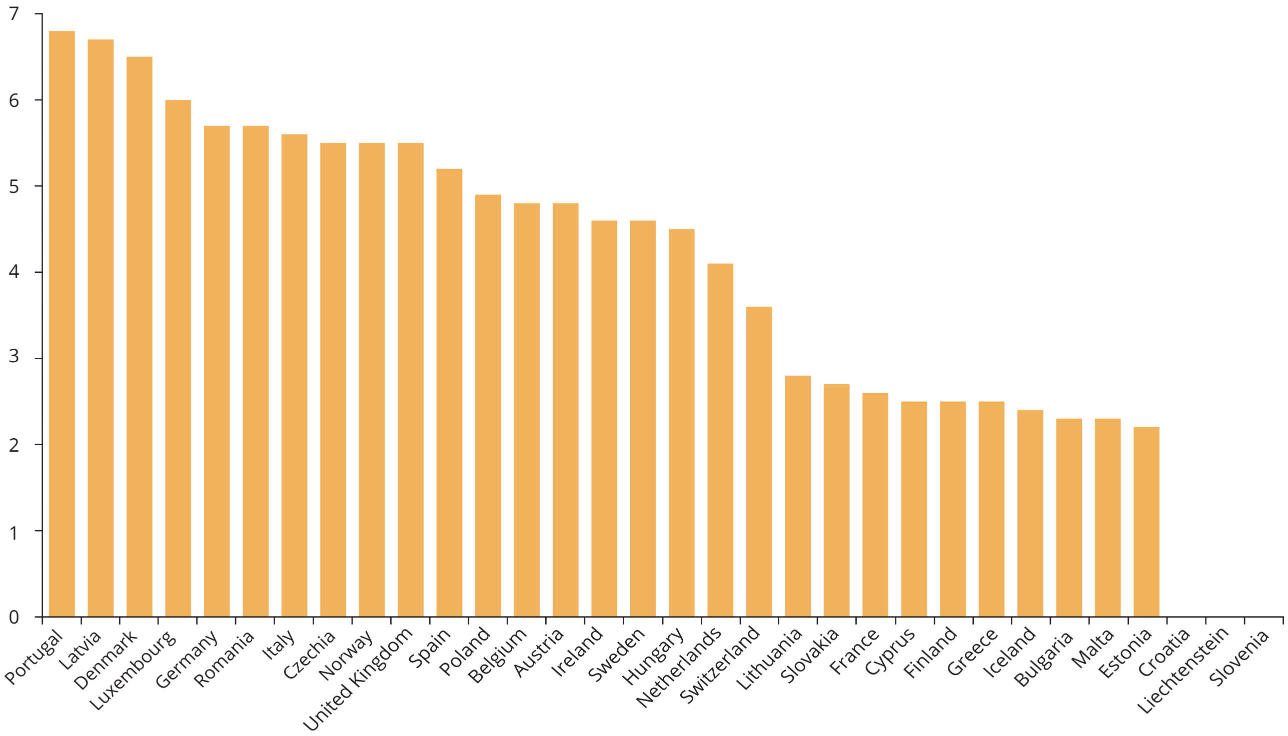
Some countries such as the United Kingdom are already taking action to protect children from aircraft noise (Box 4.1).

Figure 4.2 Estimated number of children aged 7-17 years suffering from reading impairment due to aircraft noise, 2017



Note: Estimations based on methodology described in ETC/ACM (2018).

Figure 4.3 Estimated percentage of children aged 7-17 years suffering from reading impairment due to aircraft noise of all children living in affected areas, 2017



Note: Estimations based on methodology described in ETC/ACM (2018).

Box 4.1 Reducing the impact of aircraft noise on children using eco-friendly shelters in outdoor spaces

Heathrow airport in the United Kingdom launched an innovative scheme, to provide pupils in schools affected by flight paths with noise respite. The airport provided financial support to local schools to fund the cost of building shelters to reduce noise during outdoor lessons or breaks. This was one of the airport's commitments to exploring new ways to reduce the impact of aircraft noise on children.

Since then, several schools — which are located directly under the flight paths of Heathrow's runways — installed 'adobe domes' in their playgrounds. The structure, which is made from long tubes filled with soil, gives a sense of being outside, because it has no doors — and yet it reduces the noise from overhead aircraft significantly. Inside the main dome, classes of up to 30 can be seated, and the dome supports the delivery of the school's well established and outstanding Earth curriculum, which is based on real learning experiences, mainly in the outdoor learning environment. The shelters were constructed from coiled bags of earth (with white plaster walls), which reduce overhead aircraft noise by 17 dB for the pupils inside. The adobe domes, originally designed by an Iranian architect, Nader Khalili, for lunar settlements, were first deployed in a refugee crisis after the Gulf War. The structures are most commonly used for temporary settlements in earthquakes and emergency zones.

The teachers have reported that the domes substantially reduce noise; although the planes can still be heard, one can hear and talk with other people inside. The domes are being used for creative play or as a space in which pupils can have a quiet chat with their friends. The domes also provide respite from the sun, encouraging outdoor play.

Source: Heathrow Airport Limited (2013).

Image: © Heathrow Airport Limited.

5 Effects of noise on biodiversity

Key messages

- Anthropogenic noise not only affects species sensitive to noise, but has impacts on a wide range of terrestrial and aquatic species that inhabit very different ecosystems.
- Anthropogenic noise causes a range of physiological and behavioural responses in terrestrial and marine wildlife, which can lead to reduced reproductive success, increased mortality risk and emigration, resulting in decreased population densities.
- Although the responses to noise are very much species dependent, effects can start to appear at levels as low as 40 dB(A) for terrestrial animals. In addition to levels of noise, impacts may also depend on noise frequency and type.
- At least 19 % of nature protection areas covered by Natura 2000 are located in areas where noise levels are above the Environmental Noise Directive reporting thresholds because of roads, railways and aircraft.

5.1 Impacts of noise on terrestrial and marine wildlife

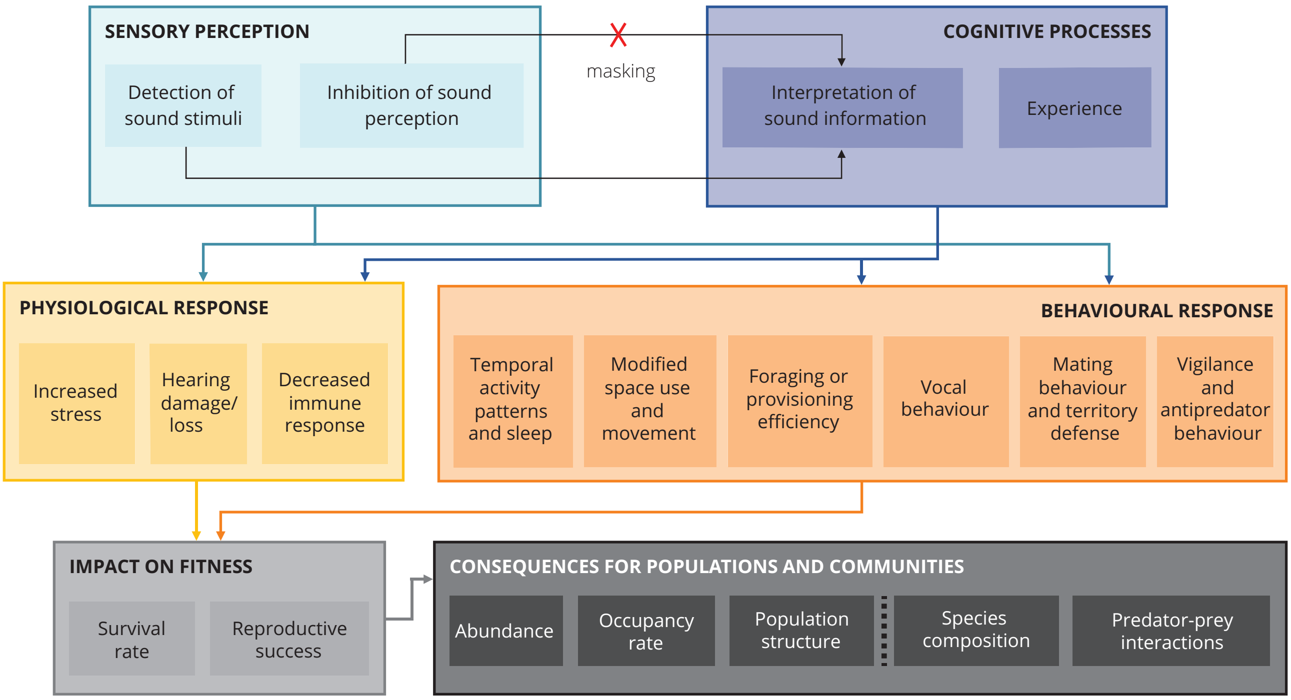
Although the main objective of the Environmental Noise Directive (END) is solely to reduce the harmful effects of noise on human health, noise from a variety of transport and industry sources also affects wildlife. Whether in the terrestrial or the marine environment, many species rely on acoustic communication for important aspects of life, such as finding food or locating a mate. Anthropogenic noise sources can potentially interfere with these functions and thus adversely affect diversity of species, population size and population distribution.

The effects of noise on animals may manifest in both physiological responses and behavioural responses (Figure 5.1 and Table 5.1). With regard to the former, some studies have observed that noise may cause stress, hearing damage and a reduced immune system in animals. For instance, a study conducted in France showed that traffic noise produces stress responses in frogs that may alter their metabolism and immune system as well as their vocal sac colouration (Troïanowski et al., 2017). Birds have also shown signs of chronic stress, such as skewed stress hormone levels, distraction and hypervigilance, when exposed to noise pollution (Kleist et al., 2018). Even more detrimental effects, such as hearing damage, have been observed in whales, as a result of very high noise levels generated by freighters in crowded shipping lanes, underwater drilling and blasting, and sonar devices used to hunt for submarines (Aguilera Hellweg and McCarthy, 2002).

There is a wide range of impacts that involve behavioural responses in animals. It is well documented that noise may cause changes in activities and sleep patterns, alterations in space use and movements, changes in the efficiency of foraging and provisioning of young, changes in vocal communication and mating behaviour as well as changes in territorial defence, vigilance and anti-predator behaviour. For example, in the case of birds, they were shown to avoid places with high levels of traffic noise, as it is believed that noise from roads makes it harder to detect predators and masks their singing (McClure et al., 2013). Their singing behaviour seems to be altered when they are close to noise sources. In particular, birds' dawn choruses were found to begin earlier in areas close to airports and roads (Arroyo-Solís et al., 2013; Dominoni et al., 2016).

Other effects on their singing include singing shorter songs and raising the frequency of their calls to reduce acoustic masking (Slabbekoorn and Peet, 2003; Gentry et al., 2018). Not only their singing but also their ability to predict other birds' aggressive intent has been found to be affected by noise (Kareklas et al., 2019). However, although there is substantial evidence that noise affects many behavioural responses in birds, it has been more

Figure 5.1 Mechanisms involved in the impact of anthropogenic noise on wildlife



Note: Masking effect: when the noise is close, it reduces an individual's ability to hear the sounds of others.

Source: Adapted from Francis and Barber (2013).

difficult to establish a relationship between noise and a decrease in populations (Summers et al., 2011)

A wide range of negative behavioural and physiological responses has been recorded in a variety of marine species. The effects observed in marine mammals include changes in vocalisation, stress, changes in respiration, increased swimming speed, orientation away from the sound source, sudden and longer dives, shifts in migration paths, strandings, changes in foraging and breeding behaviour, and auditory physiological damage (ETC/ICM, 2019). Chronic exposure to noise affects fish and invertebrates in a similar way and can result in impaired growth and reproductive processes, stress, an increase in heart rate, increased motility, migration and hearing loss (Weilgart, 2018).

These physiological and behavioural responses can lead to reduced reproductive success, increased mortality risk and emigration, resulting in reduced population densities (Francis and Barber, 2013). However, the effects of traffic noise on animals vary markedly among individuals as well as within species, owing to a variety of factors, including age, sex, sensitivity and prior exposure. Likewise, the impacts also depend on noise characteristics, such as noise intensity, duration, noise frequency and the type of noise. Therefore, as a result of these differences between species and between noise characteristics, it has been difficult to set a noise level that avoids ecological consequences, although, at least for terrestrial environments, effects have been documented for low levels of environmental and transport noise starting between 40 and 50 dB(A) (Shannon et al., 2016). Studies also indicate that biological responses of marine wildlife can occur at noise levels commonly emitted by underwater sources, such as shipping, oil and gas prospection, sonars, pile driving, dredging devices, naval exercises and offshore windmills (Shannon et al., 2016).

However, despite observed differences in impacts on different species and across different noise sources, there is substantial evidence that anthropogenic noise not only affects a few species regarded as sensitive to noise but a wide range of terrestrial and aquatic species that inhabit very different ecosystems (Kunc and Schmidt, 2019).

Table 5.1 **Effects on terrestrial and marine wildlife due to general background, transport and industrial noise**

Terrestrial	Birds	Changes in singing and communication behaviour
		Changes in spatial distributions and movements
		Reduced breeding
		Effects on physiological development
		Increased stress levels
		Reduced reproductive success
		Decline in species diversity
		Changes in distribution and abundance.
		Changes in community species
	Mammals	Changes in vocal and communication behaviour
		Reduced foraging
		Increased stress levels
		Reduced reproductive success
	Reptiles and amphibians	Changes in vocal and communication behaviour
		Difficulties in locating mates
	Invertebrates	Changes in mate attraction behaviour
Marine	Fish	Changes in spatial distributions and movements
		Changes in territorial and social behaviour
		Reduction in detection of communication signals
		Increased stress hormones
		Temporary hearing loss and damage to ears
		Reduction in local abundance and catch rate
	Mammals	Changes in vocal and communication behaviour
		Changes in time spent feeding and milling
		Loss of communication space
		Changes in spatial distributions and movements
		Increased stress hormones
		Shift in hearing thresholds
	Invertebrates	Increase in larvae settlement
		Disruption of foraging and anti-predator behaviour
		Damage to sensory systems
		Development delay and body modifications

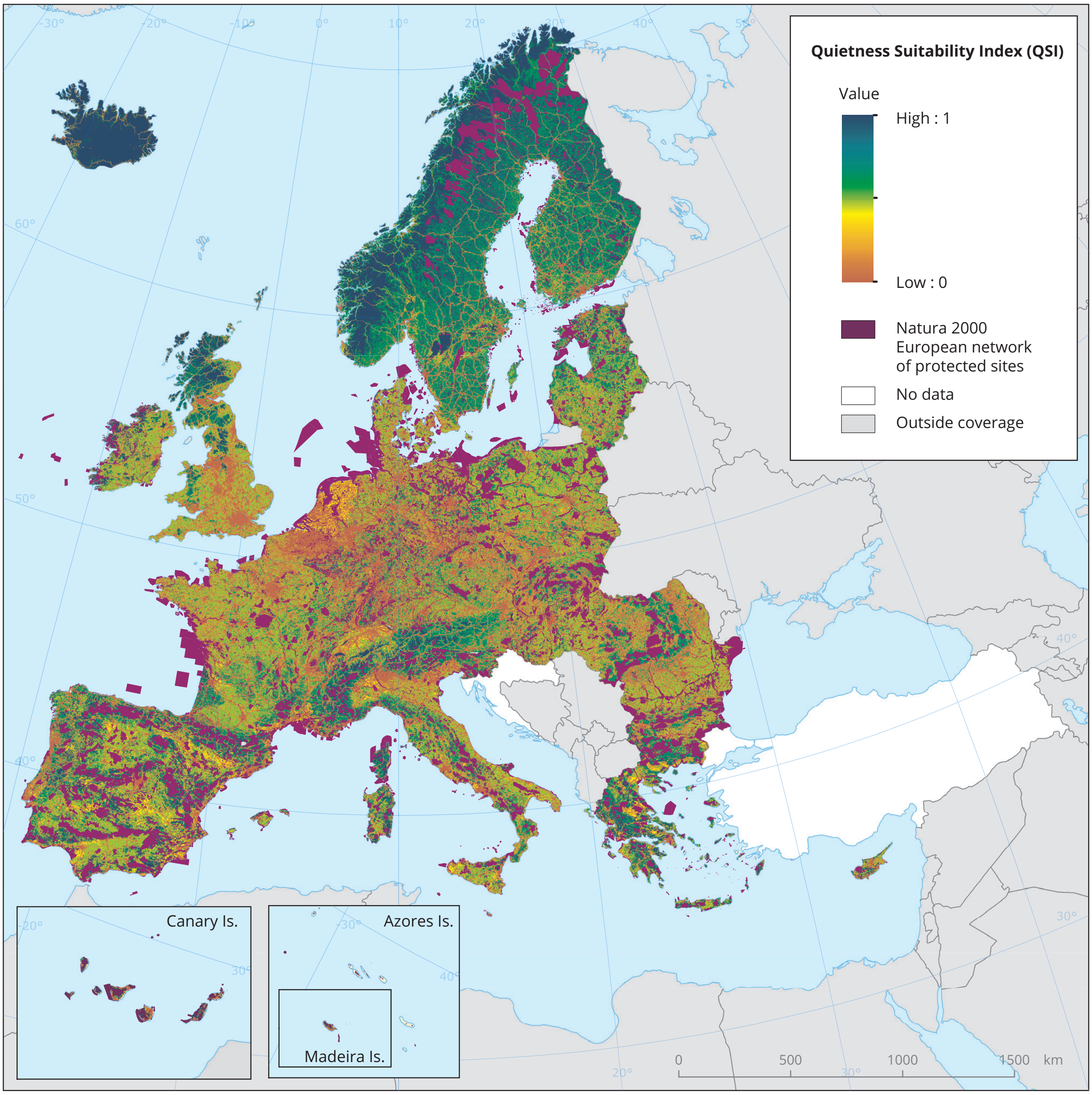
	Physiological response
	Behavioural response
	Impact on fitness
	Consequences for population and communities

Sources: Adapted from Francis and Barber (2013) and Shannon et al. (2016).

5.2 Pressures on wildlife due to noise and policy responses

There is currently no specific EU noise legislation aimed at protecting terrestrial wildlife from noise exposure. The obligations under the END mainly focus on reducing the impact of environmental noise on human health and well-being by reducing noise from roads, railways, airports and industries to levels below 55 dB L_{den} and 50 dB L_{night}. However, these are human-based impact indicators and may not be entirely comparable with the ones used to assess the impacts of noise on animals (e.g. L_{eq}, L_{max}). Nevertheless, effects generated at levels below the END thresholds may be possible, given that some studies recorded effects between 40 and 50 dB L_{Aeq}. The END recognises the need to preserve areas of good acoustic quality, referred to as 'quiet areas', to protect the European soundscape, but it does not make a link with wildlife. There are other directives, such as the

Map 5.1 Potential quiet areas in Europe, based on the QSI and Natura 2000 protected sites



Source: EEA (2014b).

Box 5.1 Quietness Suitability Index (QSI)

In 2014, the EEA developed a methodology to measure potential quiet areas in the open country called the QSI. This index is based on the combination of contour maps that exceed the Environmental Noise Directive thresholds of 55 dB L_{den} and land use and land cover elements that indicate naturalness using the hemeroby index. This index ranges from 0 (noisy areas) to 1 (quiet areas). Using this methodology, the EEA derived a map at European level showing potential quiet areas, to obtain complete European coverage when contour maps were not available.

Source: EEA (2016).

Box 5.2 Underwater noise

Sound travels rapidly through water — four times faster than through air. Underwater noise can be heard by marine life over distances of dozens of kilometres. In seawater the absorption is frequency dependent with higher frequencies being absorbed more than lower frequencies, but as salinity goes down this frequency dependent absorption also decreases. Underwater noise, as viewed by the Marine Strategy Framework Directive (MSFD) can be divided into two main types:

Impulsive noise: loud, intermittent or infrequent noises, such as those generated by piling, seismic surveys, and military sonar.

Continuous noise: lower-level constant noises, such as those generated by shipping and wind turbines. It is characterized by a long duration and it is also commonly defined as background noise.

Sources: UWE (2013) and HELCOM (2019).

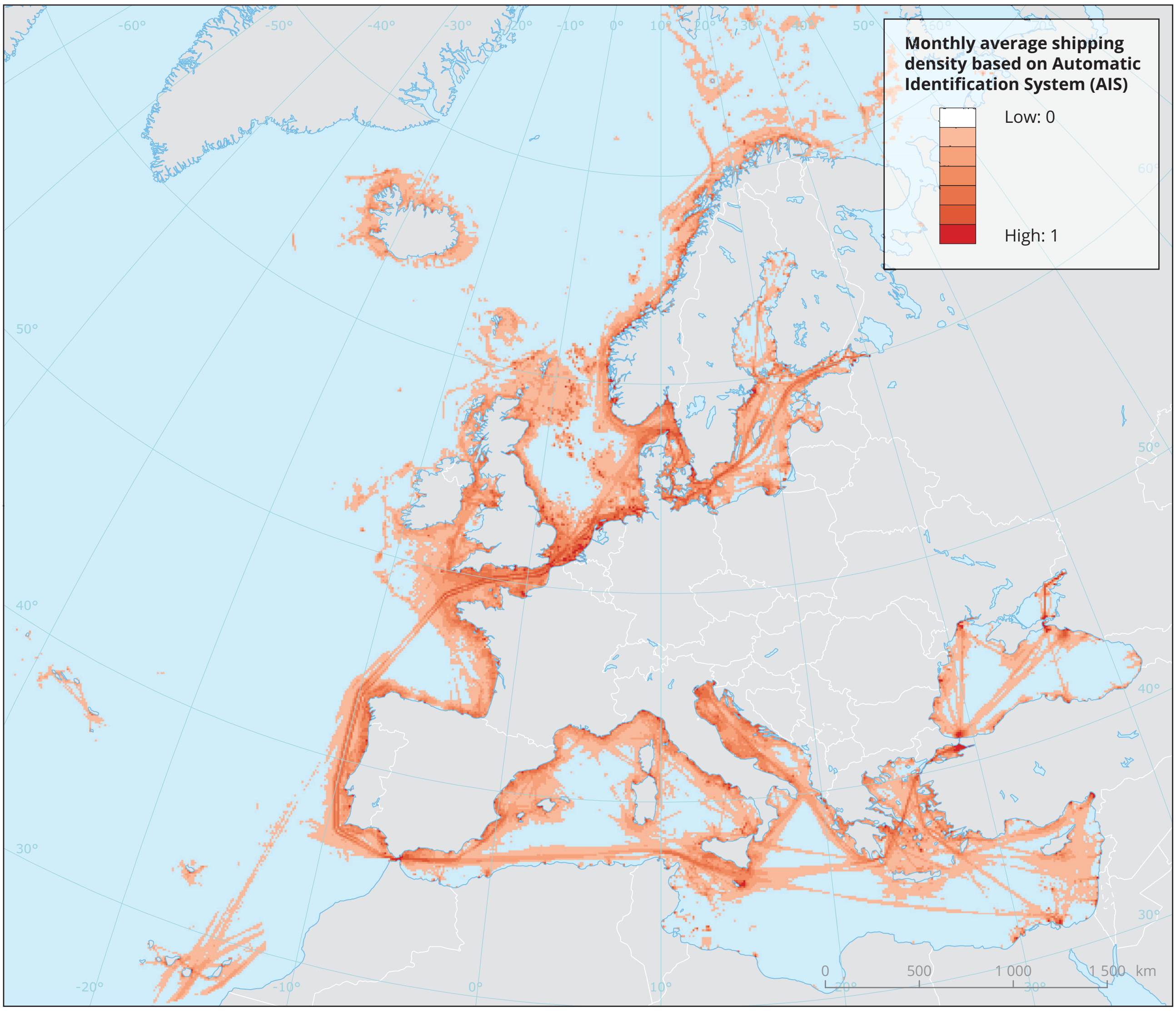
Habitats Directive (EU, 1992) and the Birds Directive (EU, 2009), which both contribute to Natura 2000, that may indirectly have a positive impact on the noise climate of natural areas.

Map 5.1 shows the potential quiet and non-quiet areas in the 33 EEA member countries (EEA-33). The protected sites in relation to Natura 2000 are shown together with the percentage of country areas in each range of the Quietness Suitability Index (QSI) (Box 5.1). The land area considered potentially noisy makes up approximately 1 594 451 km^2 across the EEA-33 (excluding Croatia and Turkey). In other words, noisy or relatively noisy areas (QSI < 0.5) account for 33 % of the EEA-33 territory. In addition to this, it is estimated that about 19 % of the Natura 2000 sites are located in areas considered noisy. It is therefore worth considering the preservation of natural acoustic conditions to limit biodiversity loss.

Policy has also been extended to further reduce impacts of underwater noise on the marine ecosystems (Box 5.2). The EU has adopted legislation, namely the Marine Strategy Framework Directive (MSFD), to achieve healthy marine systems by 2020 (EC, 2008). One of the objectives that needs to be fulfilled under the MSFD to achieve a good environmental status of EU marine waters is that underwater noise should not 'adversely affect' marine life (EC, 2008, 2016b). Shipping organizations are also concerned about this issue: in 2014, the International Maritime Organization issued guidelines on reducing noise from vessels.

Continuous underwater noise can be generated by maritime traffic, offshore platforms and energy production, as well as other industrial activities in which continuous drilling and dredging occur. Continuous underwater noise produced by maritime traffic is found across the entire European marine area (Map 5.2). Around 9 % of Europe's sea area is estimated to be exposed to very high density traffic, with the largest area of such traffic being the Mediterranean Sea (27 %), followed by the Baltic Sea (19 %) (HELCOM, 2018; ETC/ICM, 2019). European maritime traffic is expected to increase (EC, 2011, 2013), which may result in an increase in underwater noise unless it is minimised by effective technical measures. Although pre-determined routes and waterways regulate

Map 5.2 Estimated distribution of continuous underwater noise, using shipping traffic density in 2017



Notes: AIS based vessel density dataset used as a proxy for continuous anthropogenic noise. The index is based on the Log transformed monthly average shipping density per 10 × 10 km grid. It is calculated with the number of hours per month that ships spent in each kilometre square.

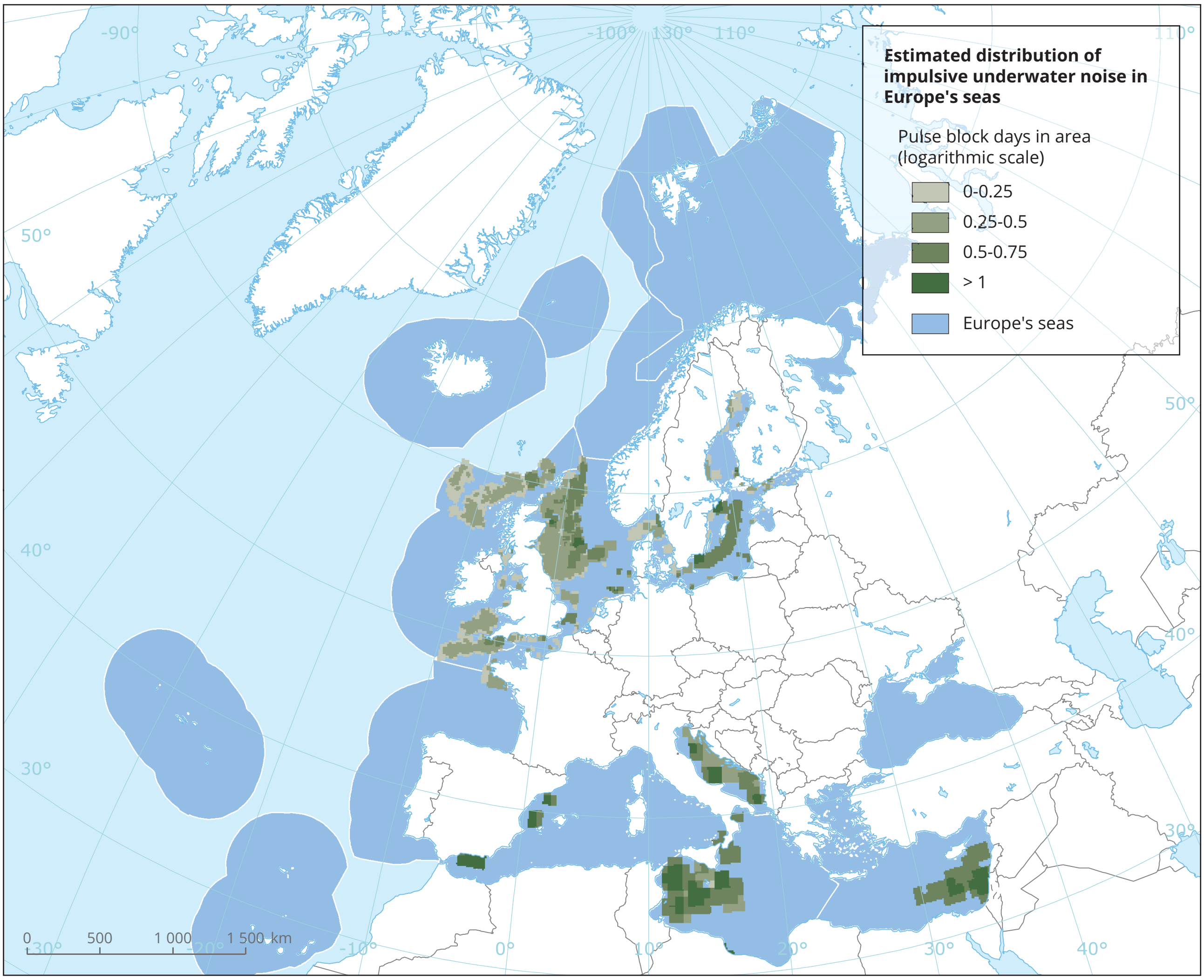
Sources: EMODnet (2019) and ETC/ICM (2019).

shipping traffic, low-frequency shipping noise can be perceived across vast distances, so much so that large areas are affected by permanent noise from ships (BFN, 2019). Criteria for the monitoring and assessment of the adverse effects of continuous underwater noise are under development within the framework of the MSFD and Regional Seas Conventions (TG Noise, 2019).

Impulsive noise — such as that produced by pile driving for onshore and offshore construction (e.g. wind farms), seismic surveys (using air guns) to inspect subsea oil and gas deposits, explosions and some sonar sources — is spatially more restricted but still found in 32 % of the Baltic Sea, 18 % of the Mediterranean Sea and 5 % of the North-East Atlantic Ocean (ETC/ICM, 2019). Data from impulsive noise registers in Europe's seas are shown in Map 5.3.

A number of measures to reduce noise for people are used (e.g. noise barriers, low-noise pavements,

Map 5.3 Estimated distribution of impulsive underwater noise in Europe's seas between 2014 and 2016



Notes: Approximate distribution of impulsive noise pressures measured as 'pulse block days' in a grid cell of 10 × 10 km. Values are shown in logarithmic scale.

Source: ETC/ICM (2019), ICS (2016) and Maglio et al. (2016).

traffic calming); however, there is limited evidence of their effectiveness for wildlife. Studies in this area recommend the use of physical barriers, geographical and temporal restrictions on human activity and quieter technologies as noise mitigation measures for wildlife (Shannon et al., 2016). Although the use of noise barriers has been suggested as the most suitable to protect roadside habitats, it has been reported to have had some drawbacks, including fragmentation or collisions, particularly with transparent barriers used to maintain visibility (Mitrus and Zbyryt, 2018). Noise barriers are also recommended for mitigating industrial activities, including in marine environments, where bubble curtains can be used to reduce pile-driving noise (Shannon et al., 2016; ACCOBAMS, 2019). Image 5.1 and Box 5.3 give examples of countries that are taking measures to protect wildlife from noise in natural environments.

Image 5.1 Example of restrictions on human activity to protect peregrine falcons from anthropogenic noise in Denmark

Image: © Miljø- og Fødevareministeriet (illustration Niels Peter Andreasen).

Box 5.3 Protecting birds from traffic noise in Sweden

The Swedish Transport Administration (Trafikverket) is taking action to protect wildlife from road and rail traffic noise in natural environments. Their work in this area is driven by national guidance — the ecological and cultural heritage standards (Trafikverket, 2015) — which state that serious noise disturbances from traffic in ecologically important natural environments must be avoided. As a result, a strategy for protecting bird species from traffic noise is currently being developed.

Through the Triekol-project, Trafikverket has already conducted several actions aimed at minimising the impact of traffic noise on birds. The first step in the process was to develop a methodology for identifying valuable natural areas where bird species may be exposed. The methodology was based on overlapping traffic noise maps exceeding the levels established by Trafikverket (see table below) for areas of valuable bird habitats, such as grasslands, marshes, lakes and forests.

Guideline values for noise and vibration for road and rail traffic established by Trafikverket (2014).

Area	Equivalent sound level (L_{eq24h}) outdoors
Parks and other recreational areas in urban settings	45-55 dB(A)
Recreational areas	40 dB(A)
Significant birdlife areas	50 dB(A)

The method also took into account current protection of the area and biotope importance. This enabled the creation of a map showing areas of valuable bird habitats that may be affected by transport noise, which serves as a national planning document.

An example of impact zones along a large road in an area of valuable bird habitats by Helldin et al., (2013).

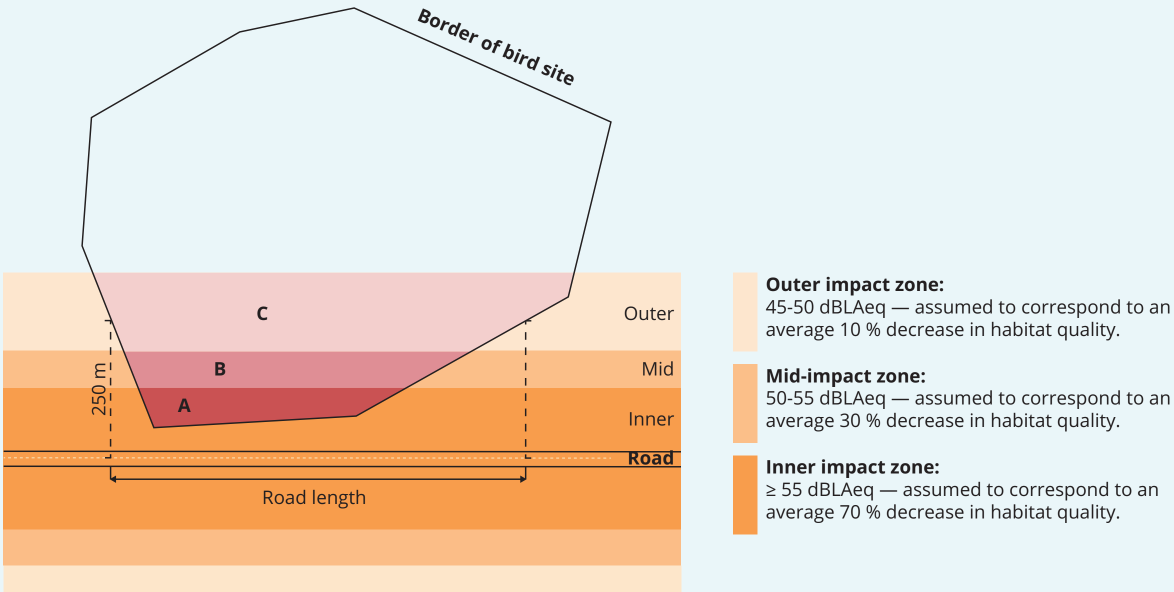


Image: Based on Helldin et al. (2013).

The second step was to determine areas where noise environmental measures should be prioritised. This was done with the help of external experts from municipalities, county administrative boards and ornithological associations. Currently, a measure selection study is taking place on a stretch of the E-6 road in the south of Sweden, where the road passes the Råån Valley, an important area of bird habitat. This study will evaluate the effects of noise mitigation measures currently used along an existing road of a bird site and will suggest noise mitigation measures that are functional for birdlife.

Source: Triekol (2017).

6 Quiet areas

Key messages

- A significant number of countries, cities and regions have definitions of quiet areas in place as well as selection criteria for designating them. However, to date, the designation and protection of quiet areas has mainly taken place in cities, with more progress needed in designating and protecting quiet areas in the open country.
- The availability and accessibility of quiet areas in cities, including residential and green areas, is highly dependent on transport infrastructure, particularly on how the location of roads and airports affects the structure of the urban environment.
- The presence of quiet areas within a city does not guarantee the accessibility of the population to these areas, which suggests that the designation of quiet areas in cities requires accessibility aspects to be taken into account.

6.1 Designation and preservation of quiet areas in Europe

Noise pollution is caused by a variety of sources and is widely present not only in the busiest urban environments but also in natural environments. Quiet areas offer low sound levels from traffic and human activities, providing relief from environmental stress and opportunities to rest and relax. Apart from the physical and mental health benefits for humans, quiet areas are also important for animals.

The Environmental Noise Directive (END) recognises the need to preserve areas of good acoustic environmental quality, referred to as 'quiet areas', to protect the European soundscape. It distinguishes between two types of quiet areas. Those found in urban areas are referred in the directive to as 'quiet area in an agglomeration' and those found outside urban areas are referred to as 'quiet area in open country'. However, the END does not provide a clear definition of quiet areas, which leaves countries with ample discretion in its interpretation (Box 6.1). Available guidance suggests that quiet areas are those in which noise is absent or at least not dominant (Salomons et al., 2013; EEA, 2014a). It is also understood that quiet areas generally have qualities other than low noise levels. Although people seek tranquillity, they also desire a safe and clean place with a pleasant view, preferably including green areas or water (Salomons et al., 2013). Furthermore, quiet areas are also those perceived to have a pleasant soundscape, created using natural or man-made sounds (Matsinos et al., 2017).

Although European legislation aims to reduce noise pollution and highlights the need to preserve areas currently unaffected, the designation of quiet areas in Europe is still under development, and areas identified as quiet are not always protected through action plans (EC, 2017b). Data reported as part of the END currently contain little information on how the countries, regions and cities define and protect quiet areas in their territories.

By means of a questionnaire, the EEA collected information from noise representatives of 21 countries, seven regions and 45 cities on current practices for designating and protecting quiet areas (Peris et al., 2019). The results showed that the majority of countries, regions and cities have definitions of quiet areas in place as well as selection criteria for designating them. For instance, out of the countries that responded, 85 % indicated that criteria for designating quiet areas in their territories were in place, and 60 % had designated at least one quiet area. It was also reported that the criteria used are different between quiet areas in the open country and quiet areas in urban areas. However, to date, most countries focus only on quiet areas in agglomerations.

The selecting criteria used for the designation of quiet areas within agglomerations vary widely among cities,

Box 6.1 Definition of quiet areas

Quiet areas can also be referred to as tranquil areas or calm areas, as these terms relate closely to the experience of the people using these areas. Although there is not a unique definition of the term 'quiet area', experts generally agree that a quiet area is one with a pleasant soundscape and in which noise, i.e. unwanted sound, is absent or at least not dominant. In addition to this, quiet areas generally have qualities other than low noise levels, for instance they offer a safe and clean place or a pleasant view, preferably including green space or water. These areas can be found in parks in towns, within building blocks, in courtyards, in gardens, in leisure areas, etc. In rural areas, they often coincide with natural parks or protected areas, but they may also be part of an agricultural area or unused land outside the city.

Sources: EEA (2016) and Salomons et al. (2013).

countries and regions. Background sound levels seem to play an important role in the selection criteria for designating quiet areas inside agglomerations (Table 6.1) although there is a wide variability on ranges and indicators used. However, sound levels are not the only important factor for designating these areas. Other factors taken into account to designate quiet areas are those related to visual qualities of the area, distance from the noise sources, subjective perception of the area, accessibility to the area and size of the area as well as land use type and functionality of the area (Table 6.2).

A significant number of competent authorities have made an effort to protect quiet areas. About 60 % of the cities that completed the questionnaire indicated that they are applying some mitigation or management measures to protect quiet areas in their urban areas. Most of the measures applied are very similar to those used for the management and mitigation of transport noise (Chapter 7). Urban planning measures that are being used to protect quiet areas include pedestrianisation and an evaluation of noise effects during the planning process of new infrastructure projects. Public engagement and awareness don't seem to be widely used for protecting quiet areas. A higher promotion and awareness of quiet areas could be beneficial, as cities have reported that one of the barriers to protecting quiet areas is that there is a lack of interest from the population in these areas.

6.2 Availability of potential quiet areas in cities

Noise contour maps submitted by countries under the END and land cover information were used to determine areas potentially unaffected by noise. The available noise contour maps for the sources of noise reported under the END (road, rail, air and industry sources) and the CORINE Land Cover 2018 were used. Only a small number of cities could be analysed due to unavailability of noise contour maps reported under the END. In total, 17 cities had reported all the necessary information required to undertake an analysis of the availability of quiet areas within their territory (Box 6.2). The methods employed for this assessment are described in more detail in (ETC/ATNI, 2019c).

The surface area of potential quiet areas in cities was assessed for different land cover types. Figure 6.1 shows that the percentage of residential areas that are below 55 dB L_{den} ranges from 28 % in Dusseldorf to 70 % in Hamburg. In 9 out of the 15 cities analysed, residential areas are predominantly located where levels lower than 55 dB L_{den} occur. In terms of availability of quiet areas with green/blue land cover types, we observe a variability between cities that ranges from 35 % in Cologne to 85 % in Lausanne (Figure 6.2). In all of the cities, except Cologne and Dusseldorf, the majority of green/blue land covers are located in areas below 55 dB L_{den}. Many of these results depend on the road infrastructure network in the centre of the cities and their surroundings, which can lead to the fragmentation of potential quiet areas within the agglomeration. Cities with airports within their boundaries also tend to have a lower share of quiet areas as a result of the noise contours covering an important part of the city area. However, making a comparison between cities is difficult because of the use of different noise assessment methods.

6.3 Accessibility to potential quiet areas in cities

Nearby access to both quiet spaces and green spaces has shown to positively contribute to the health and well-being of local communities (Sallis et al., 2016; Shepherd et al., 2013). Given that 72 % of the EU population resides in cities, it is

Table 6.1 Range of noise levels and noise indicators used to designate quiet areas in agglomerations

	≤ 30	≤ 35	≤ 40	≤ 45	≤ 50	≤ 55	≤ 60	≤ 65
L_{den}		■	■	■	■	■	■	
L_{day}			■	■	■	■	■	■
L_{night}	■	■	■	■	■			
$L_{evening}$		■	■	■	■	■		
$L_{Aeq,\ day}$					■			
$L_{Aeq,\ night}$			■					

Source: ETC/ATNI (2019c).

Table 6.2 Criteria for designating quiet areas in agglomerations

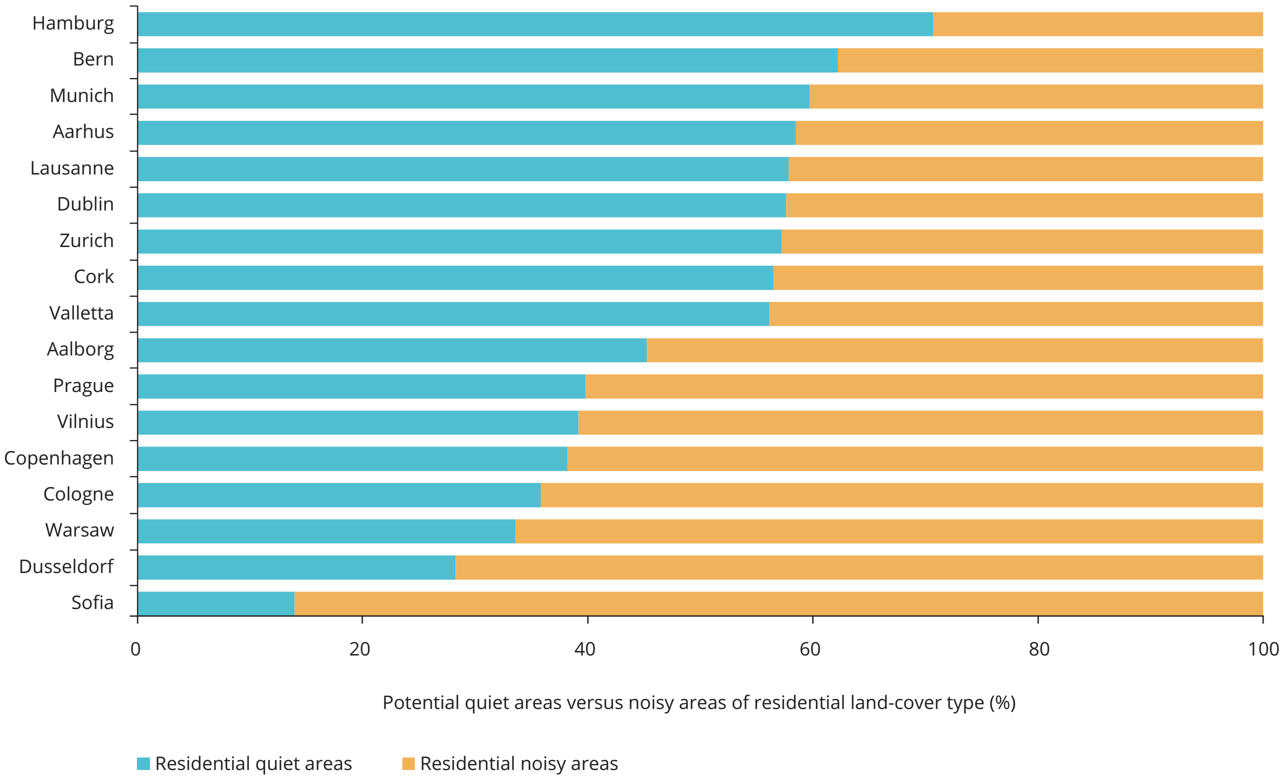
Type	Criteria
Acoustic criteria	• Noise levels across a substantial amount of the surface area that are below a certain noise threshold (Table 6.1) • Difference in noise levels between the 'quiet area' and surrounding areas — differences have been reported between 6 dB(A) and 15 dB(A)
Urban functionality	• Health-sensitive sites (i.e. hospitals, schools); recreational sites (i.e. playgrounds, sporting facilities, outdoor theatres); parks cultural heritage sites (i.e. castles, churches, archaeological sites); and public areas (i.e. urban squares, cemeteries)
Land cover type	• Green/blue land covers (i.e. a high degree of vegetation, city parks, gardens, green urban areas)
Location of the area	• A minimum distance from the noisy activities of industry and major roads • Areas within or adjacent to densely populated settlement areas or near to residential areas
Accessibility to the area	• Publicly accessible • Interconnected natural spaces connecting with interurban links to adjacent landscape areas through forests, green spaces, parks, fields and meadows • Quiet routes with a networking function — connecting routes that are away from the main traffic routes in attractive inner city open spaces
Size of the area	• Minimum size needed — different sizes have been reported from 0.3 ha to 9 ha
Visual qualities	• Areas with established scenic importance or aesthetic appeal
Subjective judgement	• Perceived as having a pleasant soundscape

Source: Adapted from ETC/ATNI (2019c).

Box 6.2 How quiet areas are defined in this assessment?

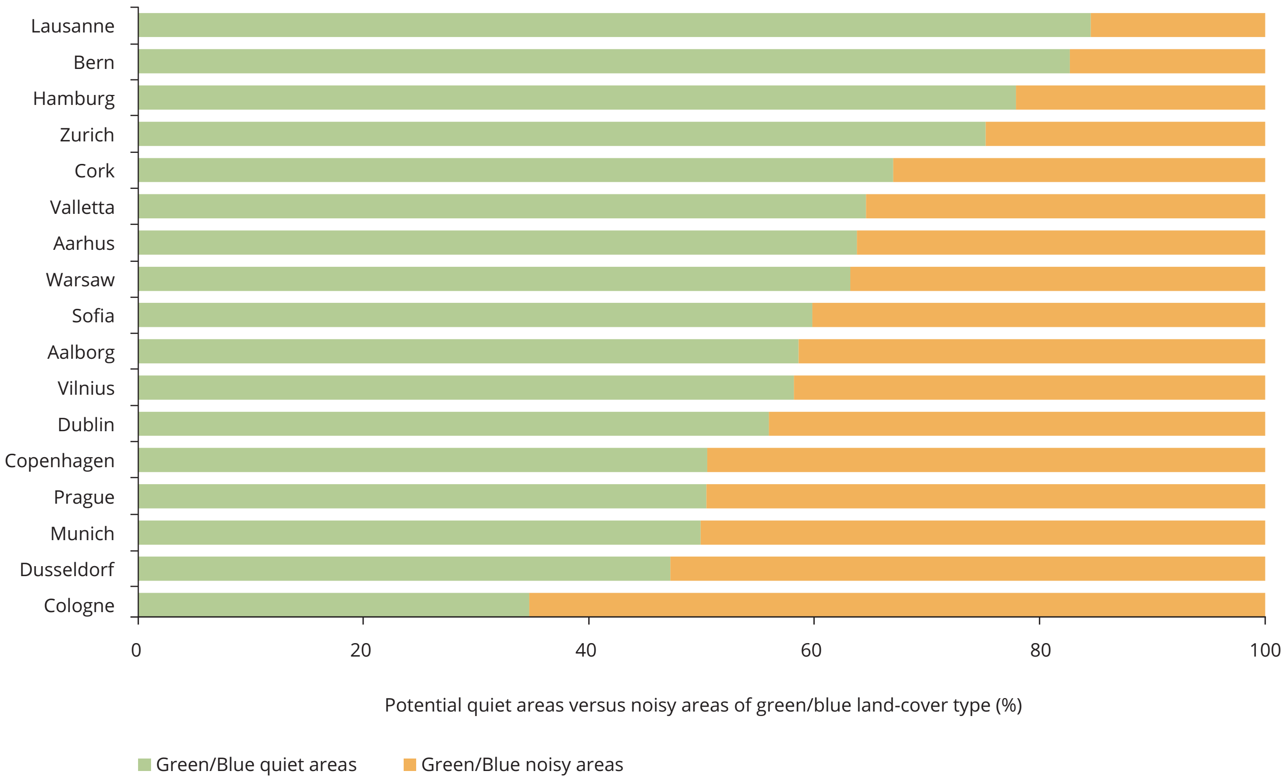
In this assessment, quiet areas were defined as those with less than 55 dB L_{den} from road, rail, aircraft and industrial sources and were classified, depending on their land cover type, as quiet areas with residential land cover or quiet areas with green/blue land cover. Health effects can occur below 55 dB L_{den} (Chapter 3). However, this assessment relies on contour maps submitted by countries under the END for which data below 55 dB L_{den} are unavailable. Therefore, since data covering all anthropogenic sources of noise and levels below 55 dB L_{den} are not available, we use the term 'potential quiet areas'.

Figure 6.1 **Percentage of potential quiet areas versus noisy areas of residential land cover type**



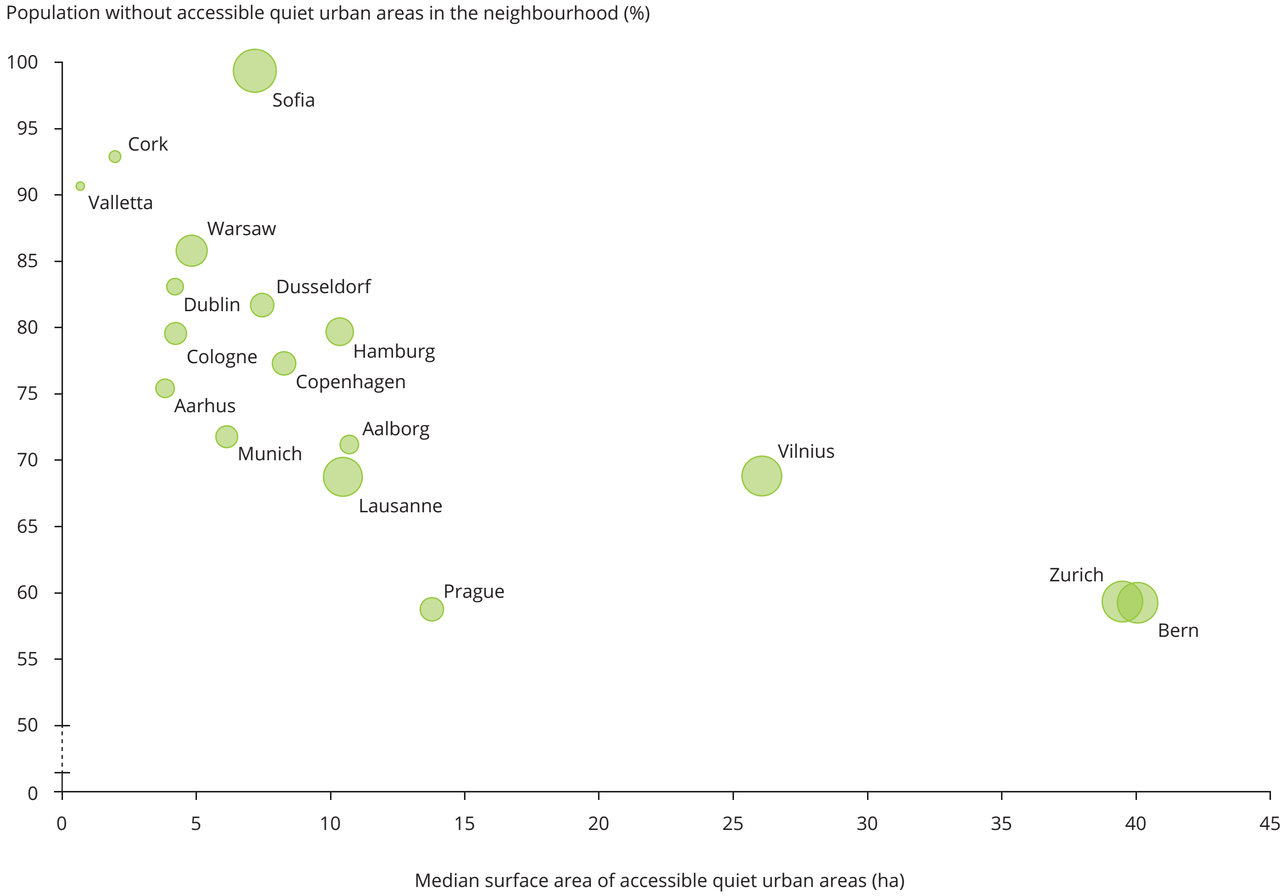
Source: ETC/ATNI (2019c).

Figure 6.2 **Percentage of potential quiet areas versus noisy areas of green/blue land cover type**



Source: ETC/ATNI (2019c).

Figure 6.3 **Proximity to potential quiet areas, percentage of the population without potential quiet areas nearby and the share of potential quiet areas in the total land area**



Notes: Bubble size represents the share of potential quiet areas over the total land area of the city. The potential quiet areas that were chosen were areas with noise levels below 55 dB L_{den} that have a green or blue land cover and extend to at least 1 ha.

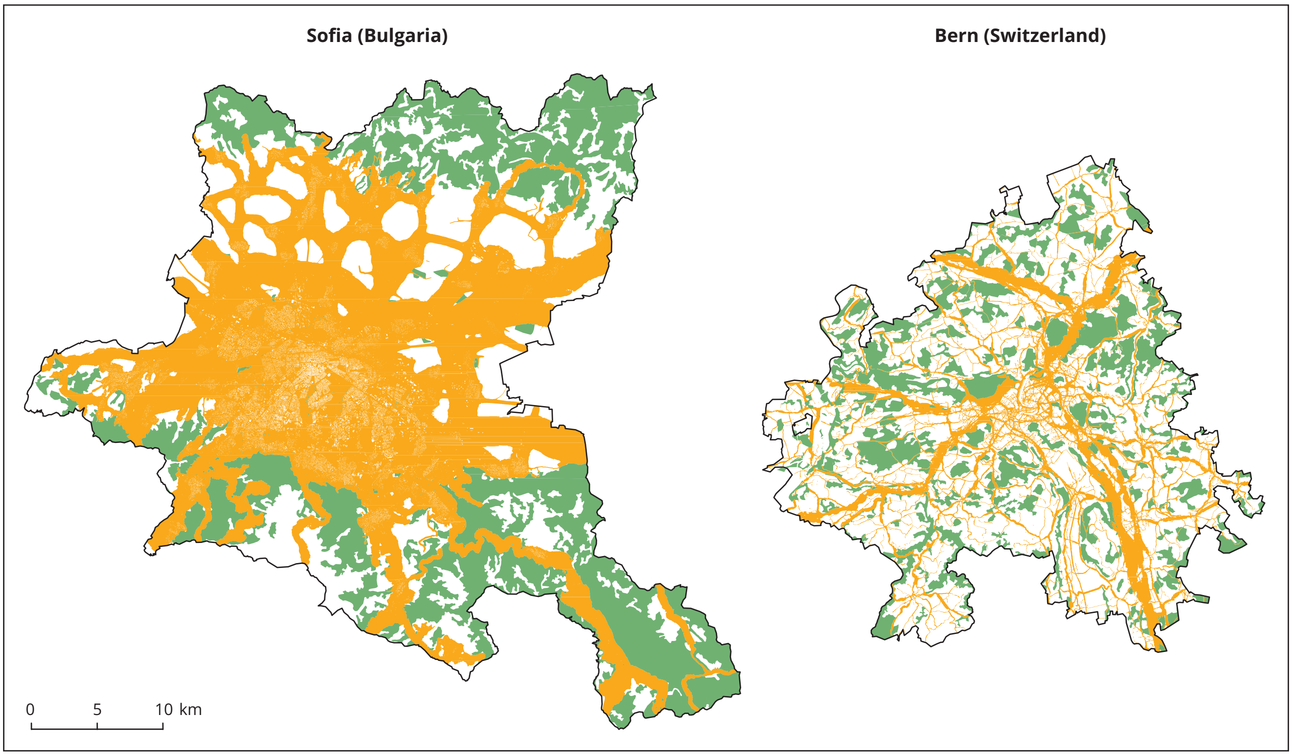
Source: ETC/ATNI (2019c).

important that cities ensure adequate access to quiet areas and green spaces, which allow physical exercise, relaxation and restoration from the stress of the city.

Accessibility to potential quiet areas was assessed in cities for which at least the contour maps for road, rail and air from the 2017 round of noise mapping were available. In total, 17 cities could be analysed. The potential quiet areas that were chosen were areas with noise levels below 55 dB L_{den} that have a green or blue land cover and extend to at least 1 ha. Accessibility was determined by calculating the number of people that can reach a quiet green or blue area within a 10-minute walk. Apart from the END noise contour maps, this analysis required other data sets, such as land cover information (EEA, 2019a), the population distribution inside urban areas (JRC, 2016) and the street network (Geofabrik, 2019). The methods employed for this assessment are described in more detail in ETC/ANTI (2019c).

Figure 6.3 shows the proportion of the population that lacks access to quiet areas, the surface area of accessible quiet areas and the share of quiet areas in terms of the total surface area of the cities investigated. Based on these data, covering 17 cities, we can see that a large

Map 6.1 **Maps of potential quiet areas for the cities of Bern and Sofia**



Potential quiet area maps for the cities of Sofia and Bern

Areas equal or above 55 dB L_{den} | Quiet areas with green/blue land cover

Notes: Areas with noise levels equal to or above 55 dB L_{den} are represented in orange. Areas in green represent quiet areas with green/blue land cover.

Source: ETC/ATNI (2019c).

proportion of the population has no access to quiet areas nearby. In most cities, between 65 % and 85 % of the population have no access to potential quiet areas of green/blue land cover nearby. It can also be seen that the median surface area of quiet areas that can be reached within a 10-minute walk is between 5 and 10 ha for most of the cities assessed. Cities with a very similar share of green/blue surface area can vary in their levels of proximity to quiet areas. This is the case for Sofia and Bern: the share of green quiet areas is 27 % and 24 % of the total land area, respectively, but only 7 ha are accessible in Sofia, compared with 40 ha in Bern. In the same way, in Sofia only 1 % of the population has access to green quiet areas, while in Bern more than 40 % of the population can find some green quiet areas within walking distance. These results highlight that, although the size of quiet areas is important to ensure good accessibility, other factors such as the location of such areas will have an impact on the number of people that can benefit from them. For instance, in the case of Sofia we observe that, while there are large quiet areas with green land cover in the periphery of the city, these areas are not accessible within a 10-minute walk for most of Sofia's inhabitants (Map 6.1). However, it is uncertain if these results are fully comparable due to the possible use of different noise assessment methods for the two cities.

7 Reducing and managing noise exposure

Key messages

- In urban areas, more than 50 % of measures aimed at reducing and managing noise focus on mitigating noise at the source. Measures at source are extensively used to reduce and manage noise in areas outside cities that are affected by major railways (52 %), major airports (70 %) and major roads (39 %). Managing and reducing noise through land use and urban planning represents a very small percentage of the measures chosen to address noise.
- Measures to target air pollution in European cities often offer co-benefits in terms of reducing environmental noise. However, not all interventions are equally effective for both stressors. Nevertheless, cost-benefit estimations for mitigation actions can be more favourable if the positive impacts of addressing both air quality and noise are taken into account. This calls for effective coordination between communities of policymakers and stakeholders working to address noise and air pollution.
- Significant delays and the poor quality of action plans suggest that countries may not have taken the necessary steps to address noise pollution.

7.1 Status of noise action planning

The END sets legally binding obligations for reduction and management of environmental noise. The noise mapping exercise is seen as a precursor for guiding the implementation of noise reduction measures which should aim to reduce the impact of noise upon the affected population. Thus, based upon noise mapping results, action plans have to be drawn up for major transport sources and the largest urban areas. Furthermore, where areas are found to be of a high acoustic quality, in other words, free from noise pollution, they should also be protected by appropriate action plans.

Based on the minimum requirements of noise action plans under the END, and as described by Murphy and King (2014), the plans generally contain the following information:

- noise reduction targets, either in terms of decibel reductions or reductions in the number of people exposed above a certain threshold;
- a description of the measures that will be used to achieve reductions;
- an identification of reduction priorities and a schedule for the implementation of measures;
- an outline of the expected costs of the measures proposed and the financial means;
- an outline of the number of people expected to experience noise reduction;
- the roles in charge of implementing and monitoring the measures put in place;
- a description of public consultation activities.

Action plans for the 2017 round of noise mapping in accordance with the END were to be concluded by 18 January 2019. However, as of April 2019, there are still a significant number of countries — 14 in total — for which such plans are missing ([1]).

([1]) 10 countries as of 1 January 2020 (EEA-33 excluding Turkey).

Box 7.1 Evaluation of action planning under the Environmental Noise Directive (END)

In 2017, the European Commission published the second implementation review of the END. The review was based on the implementation of the directive for the 2012 reporting phase of noise mapping. Where possible, it also evaluated improvements with respect to the first phase of noise mapping in 2007. The main messages regarding action planning are outlined below:

- The implementation of the action planning process was poor, with less than 50 % of required action plans completed as of November 2015. Possible reasons for the poor implementation of action planning include knock-on effects from the delays in noise mapping (as action plans need to be based on noise maps) and the short period given between the deadline for preparing noise maps and that for action plans (12 months).

- Approaches to action planning differ between Member States. This is reflected in the types of noise reduction measures identified, the balance between expenditure/non-expenditure measures and the extent to which the plans are solely strategic or also have an operational focus. Although action plans often include a summary of the consultation responses, it is often unclear how these responses have been taken into account in the plans.

- The administrative costs are low (EUR 0.15 for noise maps and EUR 0.03 for action plans per citizen, every 5 years). The cost-benefit analysis showed that, where action plans — including measures for noise management — have been implemented, the directive was efficient, with a favourable cost-benefit ratio of 1:29.

Beyond the publication of the second implementation review, the recently published *Environmental implementation review 2019* (EC, 2019) also highlights that action plans for noise management are still missing in 13 Member States, and seven countries still need to adopt the required noise action plans.

Source: EC (2017b).

It is difficult to quantify the exact level of completeness of action plans because of the diverging reporting approaches and the varying quality of action plans. For example, it is difficult to track whether all relevant major roads or railways in a country have been addressed in an action plan, owing to the varying quality of action plan reporting. In addition to this, not all the action plans submitted contain the minimum requirements established by the END, such as consultation process information or expenditures. Although it is difficult to evaluate the exact completeness of the action plans submitted under the 2017 END reporting phase, it can be highlighted that there is a significant delay in the implementation of the action planning process in a large number of countries. This significant implementation delay has already been reported by the European Commission within the second implementation report (EC, 2017b) (Box 7.1) and the latest Environmental Implementation Review (EC, 2019). Furthermore, under the END, it is not possible to track the implementation status of action plans after they have been adopted.

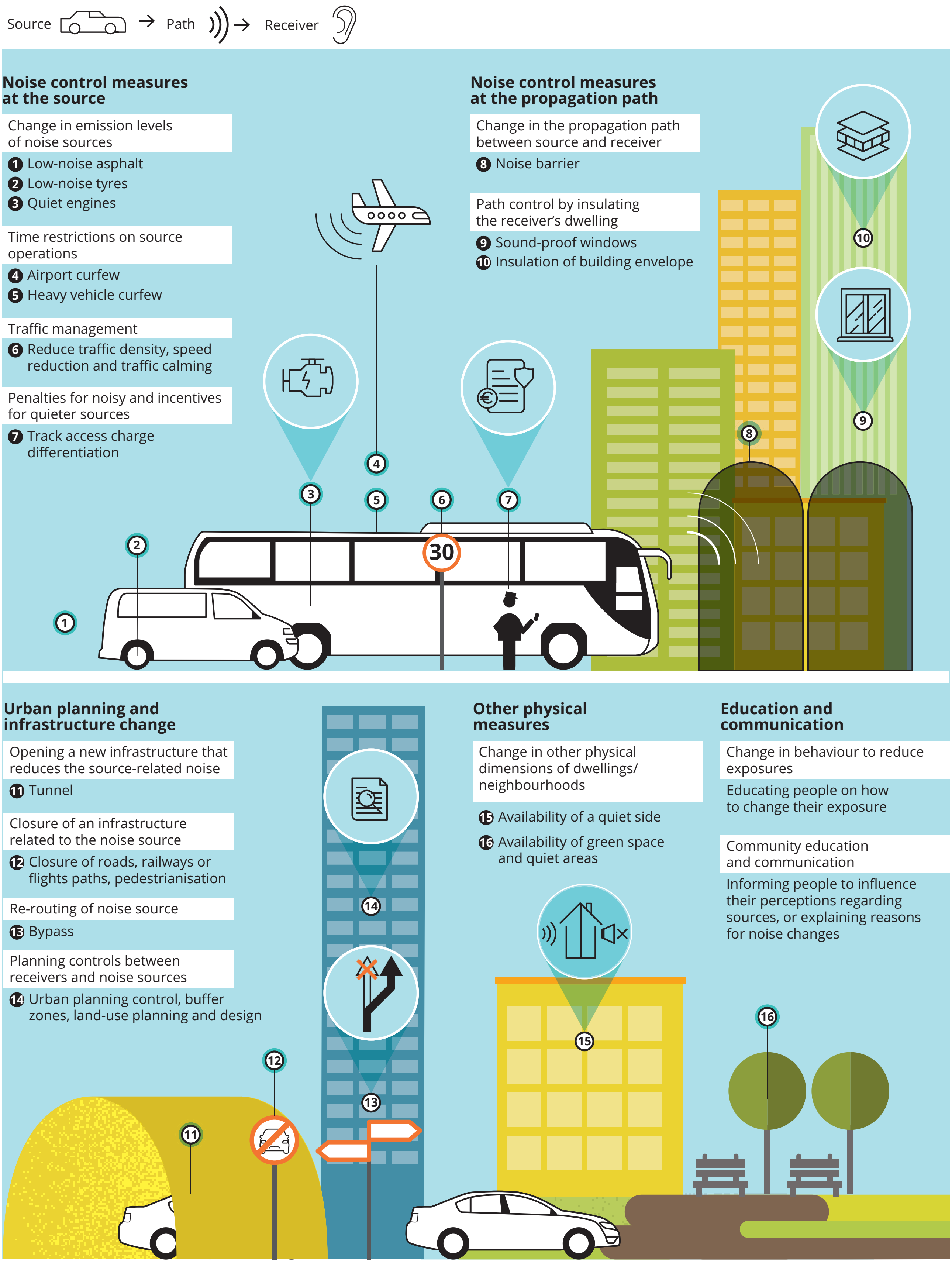
In total, as of 1 April 2019, 188 action plans covering 152 agglomerations were received from 12 countries; 45 action plans covering major roads from 13 countries; 12 action plans covering major railways from 10 countries; and 27 action plans covering major airports from nine countries. The following analysis on noise management and mitigation measures does not capture action plans submitted in formats other than those submitted using online forms, but the data used are sufficient to give a useful overview of noise abatement measures planned to be implemented in Europe.

The key management and noise reduction measures are outlined in Figure 7.1. The measures were classified following the categorisation of noise interventions used in the World Health Organization (WHO) environmental noise guidelines (2018) in which five types of categories, according to the available literature on the impact of noise reduction measures on health, are defined (Brown and van Kamp, 2017).

Figure 7.2, Figure 7.3, Figure 7.4 and Figure 7.5 summarise the main type of measures used to manage and reduce noise for major transport sources and the urban areas reported under the END action planning.

In terms of urban areas, the reported data show that noise reduction measures at the source are by far the most employed (51 %), followed by measures at the

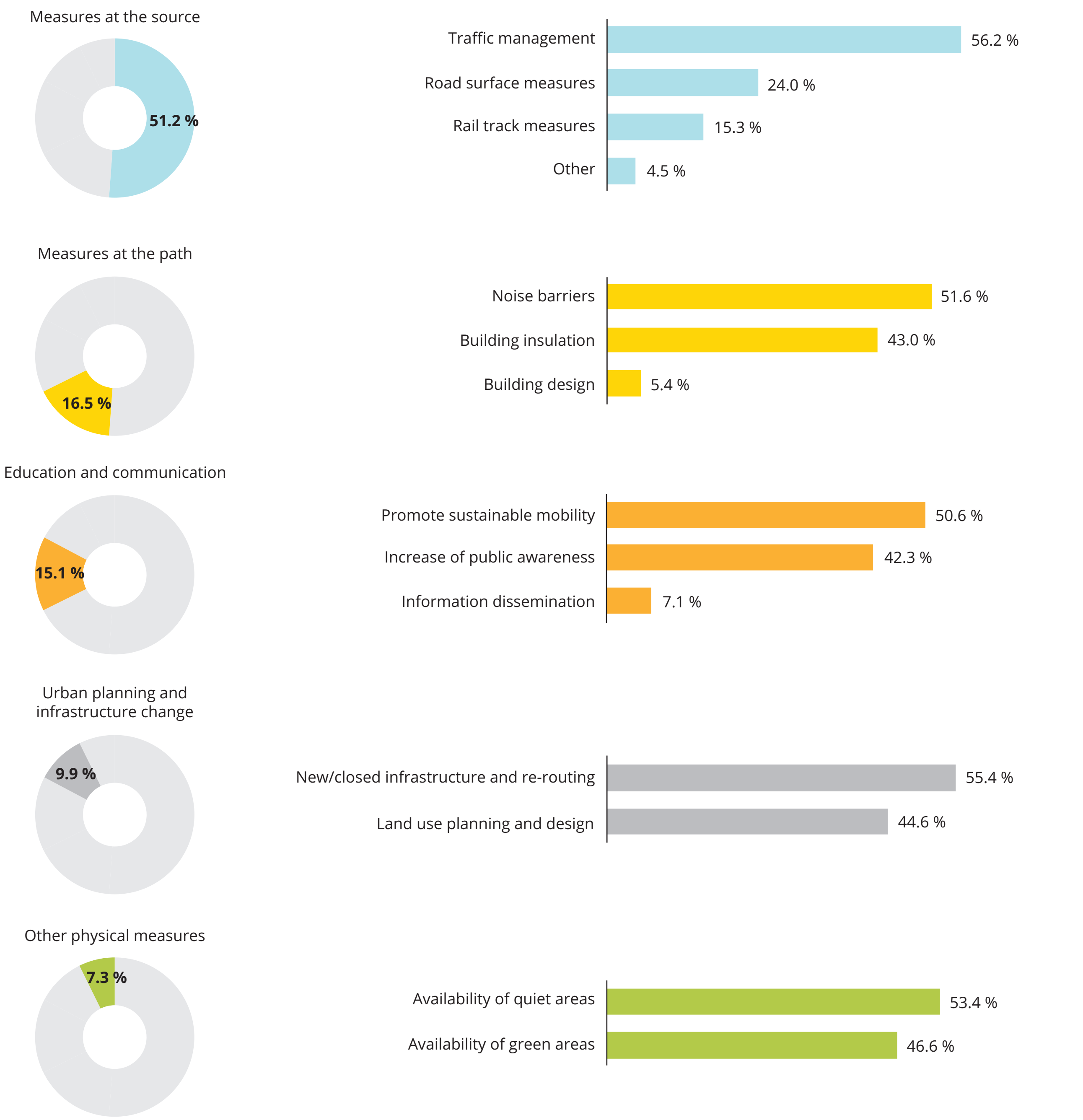
Figure 7.1 Categorisation of noise management and mitigation measures



Note: Examples of environmental noise management and mitigation measures are for illustration purposes and don't constitute an exhaustive list of measures.

Source: EEA, adapted from Brown and van Kamp (2017).

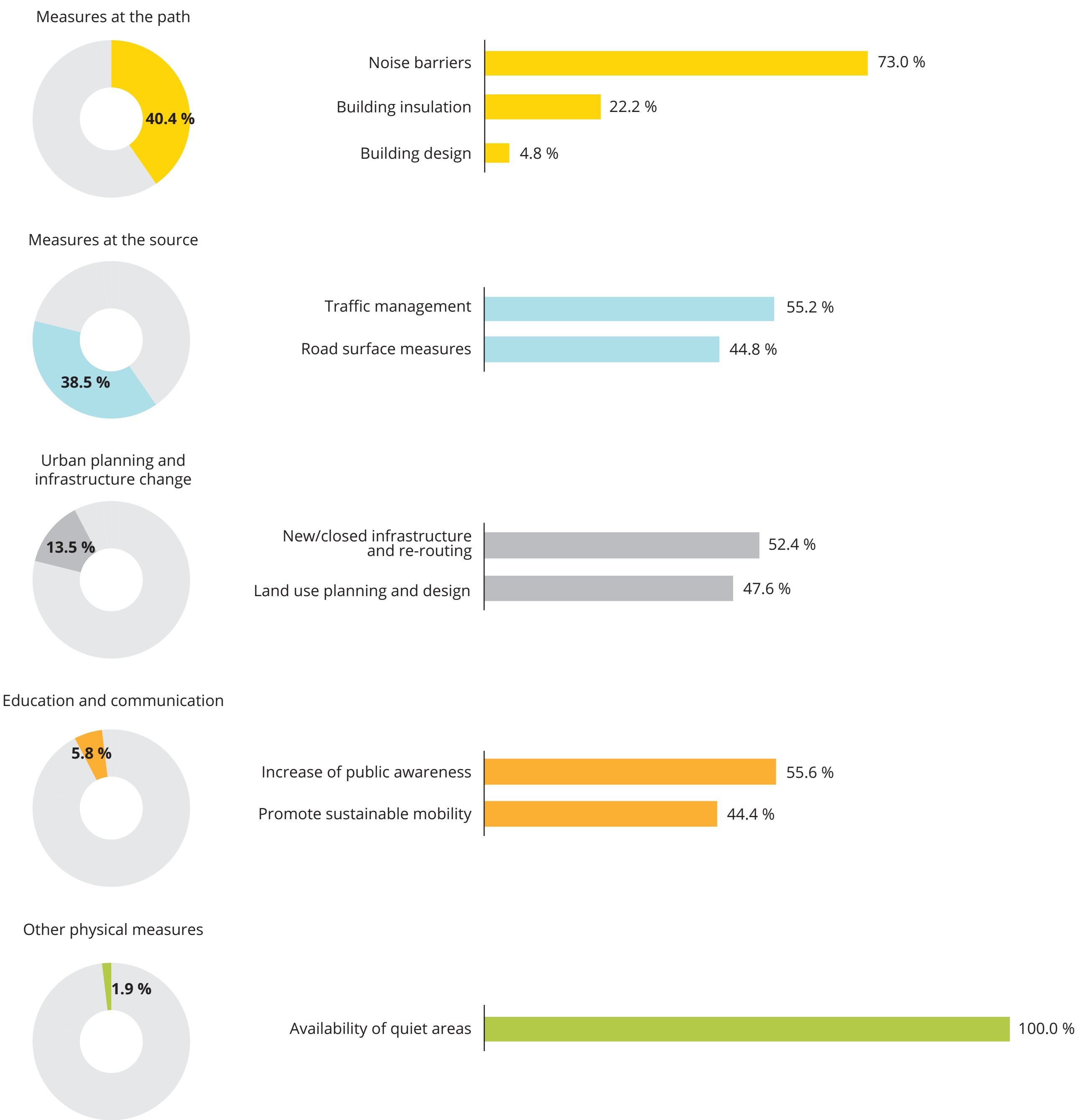
Figure 7.2 Analysis of noise action plans for agglomerations, based on the 2017 reporting round of noise mapping



Note: This analysis is based on a selection of action plan summaries.

Source: ETC/ATNI (2019d).

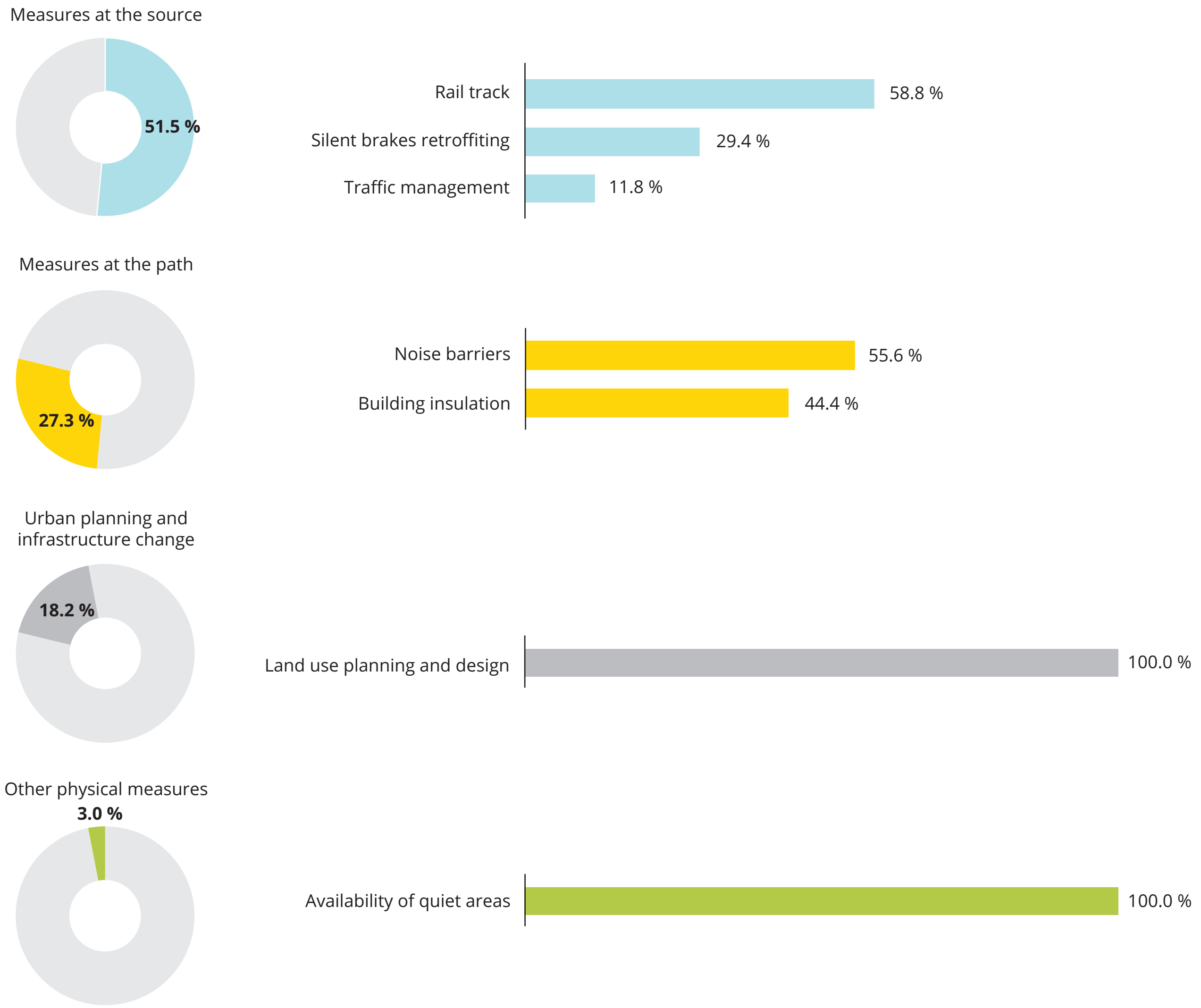
Figure 7.3 Analysis of noise action plans for major roads, based on the 2017 reporting round of noise mapping



Note: This analysis is based on a selection of action plan summaries.

Source: ETC/ATNI (2019d).

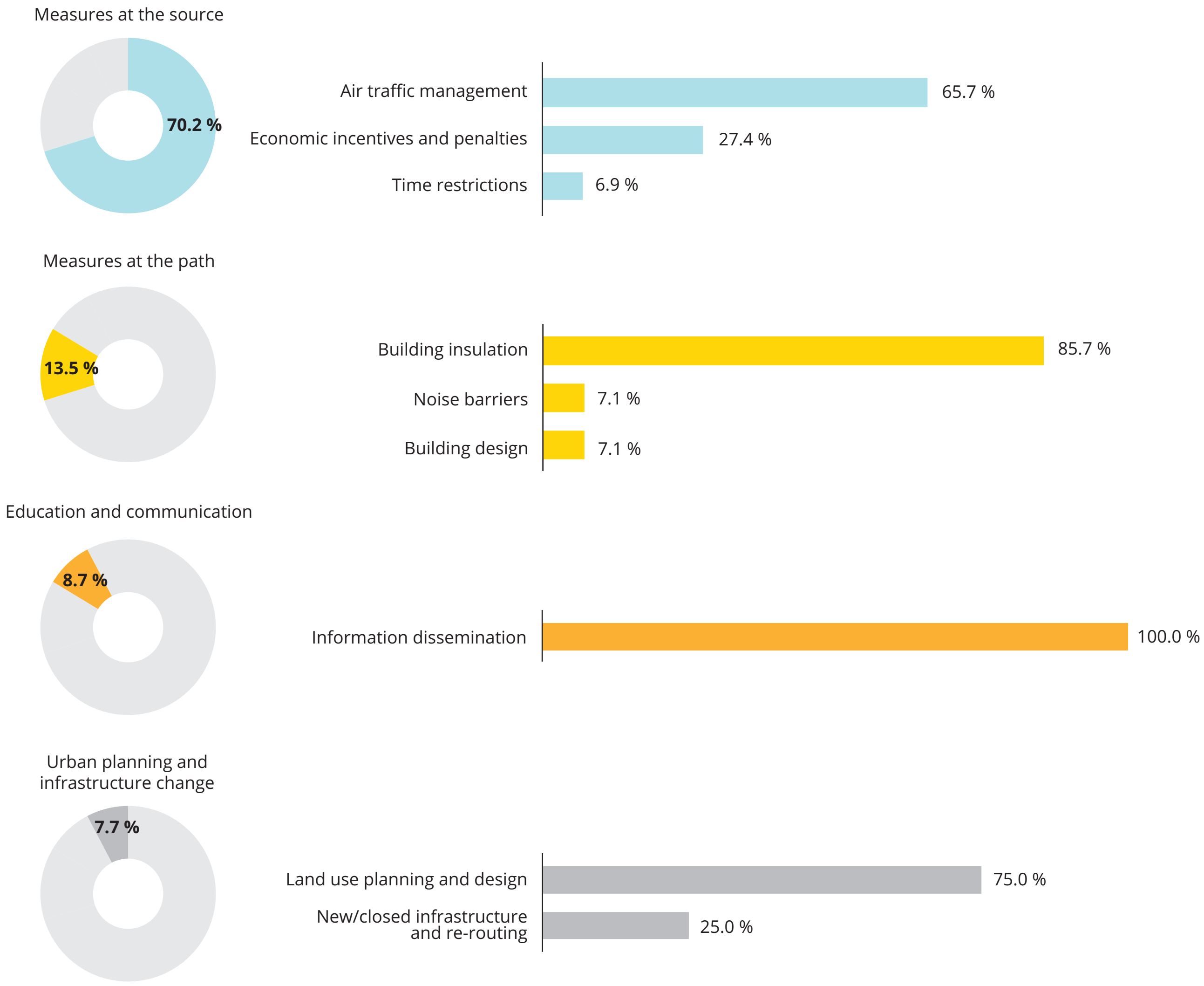
Figure 7.4 **Analysis of noise action plans for major railways, based on the 2017 reporting round of noise mapping**



Note: This analysis is based on a selection of action plan summaries.

Source: ETC/ATNI (2019d).

Figure 7.5 **Analysis of noise action plans for major airports, based on the 2017 reporting round of noise mapping**



Note: This analysis is based on a selection of action plan summaries.

Source: ETC/ATNI (2019d).

noise path (17 %), education and communication measures (15 %), urban planning and infrastructure change measures (10 %) and measures relating to other physical changes (7 %). The measures employed mainly target road traffic noise, as this is the most prevalent source of noise in cities. Among the measures tackling the source of noise in urban areas, renewing road surfaces or replacing rough pavements with smooth asphalt is the measure most used to reduce exposure to noise. Other measures highly reported in urban areas include the management of traffic flows and the reduction of the speed limit to 30 km/h. In particular, within urban areas, we can observe that there is a considerable share of measures aimed at raising awareness and changing people's behaviour in terms of using less noisy modes of transport (e.g. cycling, walking, electric vehicles).

In the case of major roads, the actions that predominate are those related to measures on the propagation path (40 %), followed by source-orientated measures (39 %). Noise barriers and traffic management measures are the most commonly reported. Actions related to land use planning and infrastructure change account for only a small percentage (14 %).

Although the installation of noise barriers — a measure at the propagation path — is a frequently reported measure for reducing noise from major railways (27 %), noise mitigation on railways is generally achieved by implementing measures at the source (52 %), such as reducing the roughness of the track by conducting regular maintenance. Unlike other major sources, the implementation of education and communication measures were not recorded for major railways.

The mitigation measures employed to reduce exposure to aircraft noise caused by major airports are of a different nature to the measures employed for road or rail. In contrast to continuous road traffic noise from a busy road, for example, aircraft noise is intermittent, i.e. consecutive aircraft noise events are usually separated by a noise-free period. Aircraft noise comes from above, making it difficult to use path measures such as noise barriers. Therefore, the most predominant measures employed to combat aircraft noise are those at the source (70 %). Among these measures, those related to traffic management as well as those incentivising or penalising certain types of aircraft are some of the most used. However, measures focusing on disseminating noise information to the public are used more frequently for major airports than for major roads and major railways. For instance, some airports tend to publish real-time noise information from monitoring stations (Topsonic, 2016).

A selection of detailed examples of the efforts countries, regions and cities are making to reduce and manage noise is shown in Box 7.2, Box 7.3 and Box 7.4.

Within the action planning process, competent authorities are required to ensure that the public is consulted about proposals for action plans and that they are given early and effective opportunities to participate in the preparation of action plans. Authorities are also required to ensure that the results of participation are taken into account and that the public is informed on the decisions taken. As it currently stands, there is a broad range of practices carried out across the countries involved, including meetings, surveys and participatory processes with a steering committee. All countries conducting public consultations have reported that they have made information on action planning available through a website. Apart from disseminating the action plans, some competent authorities also carried out other actions to involve relevant stakeholders, including local authorities, private sector and non-governmental organisations. In particular, it appears that the United Kingdom is the country with the most extensive public consultation process, involving a wider range of stakeholders and a larger variety of consultation activities.

Finally, there are recommendations and policy objectives linked to noise reduction. These include the WHO (2018) recommendations on mitigation measures for reducing health effects and the Seventh Environment Action Programme (7th EAP) objectives on noise. Table 7.1 shows that the results of the action plans are partly in line with the recommendations of the 7th EAP and the WHO (2018).

Table 7.1 Comparing END noise action plans with 7th EAP objectives and recommendations of the WHO environmental noise guidelines

	Objectives and recommendations	Results from END action plans
7th EAP	Noise reduction should be achieved by implementing measures to reduce noise at the source, including improvements in city design	Reducing noise at the source is the most extensively reported measure for all sources of noise inside and outside urban areas, except for major roads, where measures at the noise path dominate. Land use and urban planning, which are linked to city design, are also reported for all noise sources but represent a small percentage of the mitigation measures chosen to address noise problems.
Environmental noise guidelines (WHO, 2018)	To reduce exposure to noise while conserving quiet areas	Although action plans should include the number of people experiencing noise reduction, not all countries indicate these values. Actions to protect quiet areas are only mentioned in a small percentage of the action plans (i.e. 4 % in agglomeration action plans, 2 % in action plans for major roads and 3 % in action plans for major railways)
	To promote interventions to reduce exposure to noise and improve health	There is hardly any reference to the health benefits of noise reduction measures in the reported action plans. Actions targeted at increasing public awareness generally provide information on the links between noise and health.
	To inform and involve communities	Education and communication measures to reduce exposure to noise are employed in a small percentage of the total number of action plans submitted (15 % for agglomerations, 9 % for major airports, 6 % for major roads and 0 % for major railways). Public involvement in action planning is more extensive for agglomerations, where a substantial input from different stakeholders seems to have been integrated into the final action plans.
	Road noise — reduce noise both at the source and on the noise path by making changes to the infrastructure	Although changes in the noise path and at the source are the most predominant for major roads, changes in infrastructure, such as a by-pass or re-routing, account for only a small percentage of all the measures (8 %).
	Aircraft noise — reduce noise by making changes to the infrastructure (e.g. flight arrangements, opening/closing runways)	The action plans analysed show that a significant percentage of noise reduction actions (20 %) are related to regulating routes and re-routing aircraft and flight paths.

Box 7.2 Examples of noise management and mitigation measures in the EEA-33 territory

National, regional and local authorities are making significant efforts to reduce the number of people exposed to harmful levels of noise.

At the city level, planning authorities use a broad number of noise abatement measures to lower the population's exposure to noise. For instance, the establishment of cycle lanes on wide roads has been used as a standard tool for noise abatement in Berlin. The city, which has more than 500 000 people exposed to road noise levels of at least 50 dB during the night-time period, implemented an intervention programme focused on re-designing some of the streets in the city to reduce the available driving space for motorised vehicles. City streets with two lanes in each direction and with traffic reaching up to 20 000 vehicle passages a day were narrowed to single lane roads, releasing space for cycle lanes and pedestrian islands. This measure reduced the levels of traffic and concentrated it in the middle of the roadway, moving it away from residential buildings. As a result, re-designing the streets helped to reduce the number of people exposed to high night-time levels of noise by more than 50 000.

At the country level, for instance, Switzerland has developed a national action plan on noise abatement. The strategic priorities include an increase in noise mitigation measures at source, the promotion of quiet and recreational areas in settlement developments and an improvement in noise monitoring and public awareness. In particular, Switzerland will support the further development of low-noise road surfaces, the promotion of quiet vehicles and the promotion of quieter railway freight wagons.

Other noise reductions, in particular those related to railway noise, have materialised in response to national and European policy instruments. Several actions are helping to reduce people's exposure to noise due to freight trains. Among these are the revision of the Technical Specifications for Interoperability — Noise (EU, 2019a), which will make the use of quiet wagons mandatory by 2020; the introduction of noise-dependent track access charges in several countries including Austria, Germany, the Netherlands and Switzerland; and a total ban on using non-TSI NOI compliant wagons from 2020 onwards in Germany and Switzerland. For instance, these actions have helped to achieve the retrofitting of approximately 32 500 wagons in the Netherlands between 2014 and 2016. Today, on the rail network of the Netherlands, approximately 50 % of wagons are quiet. The retrofitting of silent brakes along with the installation of rail dampers and noise barriers has reduced the number of dwellings affected by noise levels of 55 dB or higher during the day-evening-night period from 75 100 to 41 600. In addition to the reduction of noise due to freight trains, the retrofitting of silent brakes in passenger trains has also contributed to achieving a reduction in rail traffic noise in countries such as the Netherlands.

Sources: References in text and information provided by the European Environmental Information and Observation Network.

Box 7.3 Noise abatement and the circular economy

Circular material use may bring economic and environmental co-benefits and is therefore a promising tool for sustainable development.

Some advances in this area involve reusing various waste materials for building noise barriers. For example, a noise barrier made of old wind turbine blades and recycled plastic was set up in the Vallensbæk municipality in Denmark. The Danish Environmental Protection Agency estimates that, by 2020, there will be 12 000 to 15 000 tonnes of fibreglass waste per year in Denmark. Therefore, fibreglass material used for wind turbine blades poses huge environmental problems because of its non-recyclable nature. This type of noise barrier has been shown to reduce noise levels by 6-7 dB in areas affected by road traffic and, therefore, represents an avenue for extending the life of such materials while lowering traffic noise.

Another similar example is the use of waste tyres for building noise barriers. Within the Runcobar project, rubberised concrete noise barriers that incorporate 40 % of rubber granules recycled from waste tyres recovered from end-of-life vehicles were developed. It is estimated that using this approach, a 3-m high noise barrier would require 46.4 tonnes of recycled rubber granules, the equivalent of 7 800 recycled car tyres per kilometre.

Sources: Gate21 (2019) and Bjegović et al. (2013).

Box 7.4 Maintenance of road noise barriers in Wallonia

Maintenance of noise abatement infrastructure is essential to guarantee the expected noise reduction. In Wallonia, there are about 60 km of noise barriers of different types (i.e. metal, concrete, timber, plexi-glass and plastic) that need to be monitored and maintained.

Image: © SPW Mobility and Infrastructures.

To identify which of these barriers needs to be upgraded or restored, the Walloon road administration has developed a tool that detects areas where intervention is needed by using the data of the Environmental Noise Directive noise maps and the data on the location of noise barriers. For instance, if the location of a noise barrier and a noise hotspot match, it means that the barrier is not sufficient to protect dwellings along the road. As a result of the analysis, it was shown that half of the noise barriers need to be upgraded (i.e. by increasing their height or length) and about one third need to be restored.

To prioritise investments, a method is needed to assess the structural, material and acoustic aspects of the noise barrier. In this way, a 'health' indicator is associated with the barrier and offers the Walloon road administration a complete overview of the state of the barriers so that they can make cost-efficient decisions.

Since this method was introduced in 2015, 10 noise barriers have been restored to increase the level of protection for the dwellings surrounding the barriers.

Source: SPW Mobility and Infrastructures (2017).

7.2 Co-benefits from air pollution measures

Interventions that reduce the adverse effects of both air pollution and noise have the potential to positively impact a larger number of people than those targeting only one environmental stressor. In general, as seen in Table 7.2, measures that may be effective in mitigating both environmental noise and air pollution from transport or industry sources include traffic calming measures, the promotion of environmentally friendly vehicles, urban planning measures, measures encouraging an increase in greenery and the promotion of energy-efficient buildings. In addition to these benefits, many of these measures can also help to reduce greenhouse gases, traffic congestion and the heat island effect as well as to promote road safety. This calls for effective coordination between different health, planning, transport and environmental protection stakeholders so that they can work together to address noise and air pollution.

However, not all interventions are equally effective for both environmental stressors. There are a few

Table 7.2 Types of air quality measures implemented or planned to be implemented by cities under the air implementation pilot (EEA, 2019b) and the co-benefits of addressing exposure to noise

Air pollution measures	Noise co-benefits	Potential effects on environmental noise
Energy-efficient buildings with insulation, renewable energy sources ([a])	✓	Sound proofing windows and doors as well as insulating outer walls of the façades exposed to noise reduces noise exposure. Thermal insulation is generally linked to better sound insulation.
Relocation of factories/industrial sites from urban areas	✓	Moving noisy factories away from densely populated areas can result in a reduction in the number of people exposed to industrial noise.
Electric buses, trams, Euro VI or retrofitted buses ([b])	✓	Electric city buses can provide a noise reduction solution at low speeds, compared with conventionally fuelled buses.
Reduced speed limits/congestion charges	✓	Lower speed limits can reduce tyre/road noise. Lower traffic volumes due to restrictions on heavy goods vehicles and incentivising the use of public transport or car sharing can reduce noise exposure.
Promotion of cycling and walking	✓	Incentivising cycling and walking may reduce the number of people using cars or buses, which may result in lower traffic volumes and noise reduction.
Low-emission zone	✓	A small reduction in noise levels can occur because of an increase in the use of electric vehicles and the removal of older, noisier vehicles.
Greening the city	✓	Green parks can reduce the negative perception of noise. Green walls, designed so that they are covered in vegetation, can also help reduce the amount of noise that enters buildings. Some types of green facades/roofs can also absorb sound, which may make streets more walkable.
Car sharing	✓	Car sharing can result in lower traffic volumes and consequently a reduction in noise.
Provision of electric vehicle infrastructure	✓	Electric infrastructure can incentivise the use of electric vehicles, which can provide a noise reduction at low speeds, compared with conventionally fuelled vehicles.

Notes: ([a]) Airtight buildings may compromise indoor air quality. Sources outside the scope of the END, such as mechanical ventilation, heat pumps and wind turbines installed in some energy-efficient buildings, may lead to increased noise levels.

([b]) Euro VI is a standard for heavy-duty diesel engines that includes more stringent emission limits for a range of air pollutants than previous standards.

Sources: Adapted from EEA (2019b) and EC (2017a).

exceptions in the measures employed to reduce noise that may have a negative impact on air pollution levels. For instance, while in general noise barriers can significantly reduce pollutant concentrations behind the barrier, during certain wind conditions the presence of a noise barrier can lead to higher pollutant concentrations behind the barrier (Baldauf et al., 2008). In addition, throughout Europe, the reduced durability of some types of noise-reducing surfaces has been encountered (CEDR, 2017). This, in turn, could increase other environmental impacts, such as emissions from maintenance activities.

To mitigate the health effects of both pollutants, Stansfeld (2015) recommends considering noise in addition to air pollution. This is because of the different dispersion patterns, e.g. noise is influenced by intervening barriers and buildings, whereas air pollution can be affected at the local scale by wind patterns. Furthermore, both pollutants affect people's health through different mechanisms. Nevertheless, cost-benefit estimations for mitigation actions can be more favourable if the positive impacts of addressing both air quality and noise are taken into account.

8 Conclusions

A better implementation of the Environmental Noise Directive (END) is needed to protect people from harmful exposure to environmental noise. Some progress has been made on implementing the data mapping and the development of noise action plans set out under the END, although significant action in many countries is still needed to ensure full implementation. For example, noise exposure data from the 2012 and 2017 rounds of noise mapping are still incomplete, with approximately 92 % and 66 % of the expected data having been reported, respectively. In the 2007, 2012 and 2017 reporting rounds, there was no common method for noise mapping in place. Therefore, countries have used different assessment methods. These inconsistencies in the quality and the quantity of the reported data make the noise situation across Europe difficult to assess. However, there are prospects for improvement. The EU has developed a common method for noise mapping (EC, 2019). As a result, it is expected that noise mapping assessments will be harmonised, making it easier to compare data across countries. Furthermore, since 5 June 2019, the EU requires all Member States to report noise data under the END through the data repository system managed by the EEA, which will result in an improvement in the quality of available data and increased transparency (EU, 2019b).

In terms of action planning, there is a more significant delay in implementation, which indicates that countries may not have taken the necessary steps to address noise pollution. There are a large number of countries for which such plans are missing as well as a large variability between the quality and the content within the action plans. These conclusions are similar to those found in the different evaluations of the directive for the previous rounds of noise mapping (EC, 2017b, 2019). The European Commission (2017b) notes that there may have been a knock-on effect of the delays in noise mapping and the short 1-year period given between the deadlines for the preparation of noise maps and for the preparation of action plans. Other reasons indicated are the limited strategic and budgetary decision-making power of some competent authorities to determine whether measures included in the action plan are realistic, feasible and can be funded (EC, 2017b).

According to the data analysed, a considerable number of people are still exposed to high noise levels. Despite efforts to achieve a significant reduction in noise pollution, through the application of the END and other EU noise-related regulations, the overall number of people exposed to high levels of noise remained mostly stable between 2012 and 2017. Therefore, the Seventh Environment Action Programme (7th EAP) objective of significantly reducing noise pollution in the EU, thus moving closer to World Health Organization (WHO) recommended levels by 2020, will not be achieved. What is more, with projections of urban growth in Europe and an increased demand for transport, an increase in the number of people exposed to environmental noise is anticipated by 2020. Similarly, longer term outlooks are not encouraging. For example, even if the objectives outlined in the White Paper *Roadmap to a single European transport area* (EC, 2011) of halving the number of conventionally fuelled cars inside urban areas by 2030 are achieved, the number of people exposed to road noise — the most prevalent source — is set to increase. Likewise, it is likely that noise outside urban areas will increase by 2030, in particular for road and rail traffic, due to an increase in the number of road and rail vehicles carrying passengers and freight. Aviation noise may stabilise, under the base traffic forecast, only if all the anticipated technology improvements stated in the *European aviation environmental report 2016* (EASA et al., 2016) are met by 2030.

Achieving the 7th EAP objectives for reducing the impacts of noise on people would have required more effective development and implementation of noise action plans in areas of concern. In the past, the implementation of action plans by countries has proven to be cost-effective. The fitness check on the implementation of the END concluded that the directive has not yet achieved its full potential, although estimations show a favourable cost-benefit ratio of 1:29 (EC, 2017b). In other words, in cases where action plans including measures for noise management have been adopted, the benefits have outweighed the costs. However, due to poor implementation of the END action planning, it is currently not possible to evaluate the number of people that are expected to experience a noise reduction when plans are finalized.

The availability of this information would permit an evaluation of noise interventions from a health outcome perspective.

The 7th EAP states that noise reduction should be achieved by implementing measures to reduce noise at source, including improvements in city design. The WHO (2018) goes further and recommends noise mitigation measures based on their effectiveness in reducing health impacts caused by noise. For example, the guidelines suggest implementing infrastructure changes such as closing runways or rearranging flight paths. Apart from achieving a reduction in aircraft noise exposure, it has been shown that such measures lead to a decrease in annoyance and an improvement in cognitive abilities in children. Similarly, and based on health outcomes, the guidelines also recommend reducing road traffic noise by using measures at the source and measures at path that implement changes to the infrastructure, such as bypasses and re-routing. Currently, within the action plans received under the END, there is a lack of evaluation of noise interventions from a health outcome perspective.

Data on action plans submitted by countries under the END show that noise reduction at the source (e.g. improvement of road and rail surfaces, air traffic management, reduction of speed limits, retrofitting, management of traffic flows) is the most extensively reported mitigation measure for all sources of noise inside and outside urban areas, except for major roads. Land use and urban planning, which are linked to city design (e.g. protecting sensitive receivers using street design and the provision of quiet zones) are also reported for all noise sources but represent a small percentage of the mitigation measures generally chosen to address noise problems. Other less cost-effective mitigation measures for managing noise are those related to the noise path, such as introducing noise barriers, and those related to the receiver, such as providing home insulation. Although these measures are considered costly and less cost-effective than, for instance, improving road surfaces, they are generally used to reduce very high noise levels in localised hotspots (Peeters and van Blokland, 2018). A way to increase the impact of noise mitigation measures while optimising costs and efforts could be to design combined strategies for mitigating noise and air pollution from traffic. This would require a coordinated and collaborative approach with relevant stakeholders.

The new data from the third round of noise mapping as well as the updated noise and health relationships provided by the WHO (2018) have allowed the quantification of the health effects resulting from environmental noise exposure. In spite of the incompleteness of the reporting, the evidence presented in this report suffices to demonstrate the scale of environmental noise pollution and highlights the importance of noise as a public health issue. Given that the WHO sets lower limits than the END reporting thresholds for the value above which health effects start to occur, the noise exposure figures presented in this report are likely to be underestimated. It is yet to be seen how national and local authorities will respond to the recent introduction of the WHO guidelines (WHO, 2018), which show that levels below 55 dB L_{den} and 50 dB L_{night} are likely to cause health problems. At the moment, noise reporting and the delivery of action plans targeting the reduction of noise below the aforementioned END thresholds remains voluntary for countries. National and local noise action plans targeted at lower levels than those outlined by the END could potentially lead to reduced environmental noise levels and subsequent benefits for health. Nonetheless, there are already policy developments within the END that respond to the introduction of the new WHO environmental noise guidelines (WHO, 2018), such as the forthcoming Annex III update, which outlines the latest exposure-response relationships. This is likely to help countries take a harmonised approach to quantifying the health effects and the burden of disease due to environmental noise.

To achieve a reduction in noise exposure and its subsequent negative health effects, actions need not always focus on areas of high noise levels. One of the WHO guiding principles (WHO, 2018) is to 'reduce exposure to noise, while conserving quiet areas'. Therefore, areas of good acoustic quality, namely quiet or tranquil areas, should be preserved. If areas of good sound quality are neglected or ignored, more people may become exposed to noise. In addition to this, a combination of green and quiet environments usually has restorative effects. People choose green and quiet environments to read and relax in as well as to escape the city buzz (Payne and Bruce, 2019). Research from the Netherlands also suggests that those living in noisy areas have a larger need for quiet areas (Health Council of the Netherlands, 2006). Hence, a reduction in potentially restorative spaces, including parks and quiet urban quarters, could result in a negative impact on well-being. Regarding the END, action plans that aim to identify and protect quiet areas within the strategic noise mapping process enable competent authorities to control the evolution of the sound quality within them. However, the END does not provide a clear definition of quiet areas, leaving countries with ample discretion in its interpretation. Therefore, practical guidance in this area has been identified as an area of further development (EC, 2017b), to help countries to fully integrate the protection of quiet areas into their action plans. Quiet areas in cities are generally those that also have other attributes such as green/blue land cover. These can be preserved by taking actions similar to those used to reduce noise. However, as seen in this report, the existence of quiet areas within a city does not guarantee that a city's population will have sufficient access to these areas, and therefore the future designation of quiet areas should take into account accessibility aspects. Furthermore, given that a quiet area can also be one with a pleasant soundscape, quiet areas in cities could also be protected by enhancing positive sounds, such as those from natural features (Matsinos et al., 2017).

Finally, apart from the effects of noise on human health, there is increasing scientific evidence regarding the harmful effects of noise on wildlife. Recent literature calls for conservation actions aimed at protecting wildlife from noise pollution (Kunc and Schmidt, 2019). Although there is currently no specific EU noise legislation aimed at protecting terrestrial wildlife from exposure to noise, the requirement for identifying and protecting quiet areas in association with the END presents an ideal synergy with the need to protect wildlife from noise and areas of valuable habitat identified by other European assessments, such as Natura 2000 protected sites. However, the END reporting thresholds may not be fully appropriate for all natural habitats.

Abbreviations

7th EAP	Seventh Environment Action Programme
AIS	Automatic identification system
BoD	Burden of disease
Corine	Coordination of Information on the Environment
DALY	Disability-adjusted life-year
dB	Decibel
dB(A)	A-weighted decibel
DW	Disability weight factor
EEA	European Environment Agency
EEA-33	33 EEA member countries: the 28 EU Member States plus Iceland, Lichtenstein, Norway, Switzerland and Turkey
END	Environmental Noise Directive
EU	European Union
EU-28	28 Member States of the EU
EU-SILC	European Union Statistics on Income and Living Conditions
HA	Highly annoyed
HIA	Health impact assessment
HSD	Highly sleep disturbed
IHD	Ischaemic heart disease
L_{Aeq}	A-weighted, equivalent sound level
L_{den}	Day-evening-night noise level
L_{day}	Day noise level
L_{night}	Night noise level
NOISE	Noise Observation and Information Service for Europe
NUTS	Nomenclature of Territorial Units for Statistics
QSI	Quietness suitability index
RR	Relative risk
SEP	Socio-economic position
TSI NOI	Technical Specifications for Interoperability — Noise
WHO	World Health Organization

References

ACCOBAMS, 2019, *Methodological guide: guidance on underwater noise mitigation measures*, No ACCOBAMS-MOP7/2019/Doc 31, Istanbul, Turkey (https://accobams.org/wp-content/uploads/2019/04/MOP7.Doc31Rev1_Methodological-Guide-Noise.pdf) accessed 2 August 2019.

ACEA, 2017, *Vehicles in use — Europe 2017*, European Automobile Manufacturers' Association (https://www.acea.be/statistics/article/vehicles-in-use-europe-2017) accessed 9 July 2019.

Aguilera Hellweg, M. and McCarthy, S., 2002, 'Killing Whales with Sound', *Discover*, April 2002.

Andersen, Z. J., et al., 2018, 'Long-term exposure to road traffic noise and incidence of breast cancer: a cohort study', *Breast Cancer Research* 20(1), p. 119 (DOI: https://doi.org/10.1186/s13058-018-1047-2).

Arroyo-Solís, A., et al., 2013, 'Experimental evidence for an impact of anthropogenic noise on dawn chorus timing in urban birds', *Journal of Avian Biology* 44(3), pp. 288-296 (DOI: https://doi.org/10.1111/j.1600-048X.2012.05796.x).

Babisch, W., 2006, 'Transportation noise and cardiovascular risk: updated review and synthesis of epidemiological studies indicate that the evidence has increased', *Noise & Health* 8(30), pp. 1-29.

Baldauf, R., et al., 2008, 'Impacts of noise barriers on near-road air quality', *Atmospheric Environment* 42(32), pp. 7502-7507 (DOI: https://doi.org/10.1016/j.atmosenv.2008.05.051).

Basner, M., et al., 2014, 'Auditory and non-auditory effects of noise on health', *Lancet* 383(9925), pp. 1325-1332 (DOI: https://doi.org/10.1016/S0140-6736(13)61613-X).

Basner, M. and McGuire, S., 2018, 'WHO environmental noise guidelines for the European region: a systematic review on environmental noise and effects on sleep', *International Journal of Environmental Research and Public Health* 15(3) (DOI: https://doi.org/10.3390/ijerph15030519).

Berglund, B., et al., 1999, *Guidelines for community noise*, World Health Organization, Geneva (http://apps.who.int/iris/handle/10665/66217) accessed 28 November 2018.

Beutel, M. E., et al., 2016, 'Noise annoyance is associated with depression and anxiety in the general population — the contribution of aircraft noise', *PLoS ONE* 11(5), p. e0155357 (DOI: https://doi.org/10.1371/journal.pone.0155357).

BFN, 2019, 'Continuous sound', BFN — Federal Agency for Nature Conservation (https://www.bfn.de/en/activities/marine-nature-conservation/pressures-on-the-marine-environment/underwater-noise/continuous-sound.html) accessed 5 August 2019.

Bjegović, D., et al., 2013, 'Innovative use of waste tyres for sustainable concrete technology', conference paper presented at: International Conference on Advances in Cement and Concrete Technology in Africa, Johannesburg, 2013.

Bocquier, A., et al., 2014, 'Is exposure to night-time traffic noise a risk factor for purchase of anxiolytic-hypnotic medication? A cohort study', *European Journal of Public Health* 24(2), pp. 298-303 (DOI: https://doi.org/10.1093/eurpub/ckt117).

Brown, A. L. and van Kamp, I., 2017, 'WHO environmental noise guidelines for the European region: a systematic review of transport noise interventions and their impacts on health', *International Journal of Environmental Research and Public Health* 14(8) (DOI: https://doi.org/10.3390/ijerph14080873).

Campello-Vicente, H., et al., 2017, 'The effect of electric vehicles on urban noise maps', *Applied Acoustics* 116, pp. 59-64 (DOI: https://doi.org/10.1016/j.apacoust.2016.09.018).

Casey, J. A., et al., 2017, 'Race/ethnicity, socioeconomic status, residential segregation, and spatial variation in noise exposure in the contiguous United States', *Environmental Health Perspectives* 125(7), p. 077017 (DOI: https://doi.org/10.1289/EHP898).

CEDR, 2017, *State of the art in managing road traffic noise: noise-reducing pavements*, Technical Report No 2017-01, Conference of European Directors of Roads (https://www.cedr.eu/wpfb-file/cedr-tr2017-01-noise-reducing-pavements-pdf/) accessed 27 October 2019.

Civil Aviation Authority, 2018, *Aircraft Noise and Annoyance: Recent findings*, No CAP 1588, Environmental Research and Consultancy Department (https://publicapps.caa.co.uk/modalapplication.aspx?appid=11&mode=detail&id=8246) accessed 14 January 2020.

Clark, C., et al., 2006, 'Exposure-Effect Relations between Aircraft and Road Traffic Noise Exposure at School and Reading ComprehensionThe RANCH Project', *American Journal of Epidemiology* 163(1), pp. 27-37 (DOI: 10.1093/aje/kwj001).

Clark, C. and Paunovic, K., 2018a, 'WHO environmental noise guidelines for the European region: a systematic review on environmental noise and cognition', International Journal of *Environmental Research and Public Health* 15(2), p. 285 (DOI: https://doi.org/10.3390/ijerph15020285).

Clark, C. and Paunovic, K., 2018b, 'WHO environmental noise guidelines for the European region: a systematic review on environmental noise and quality of life, wellbeing and mental health', *International Journal of Environmental Research and Public Health* 15(11), p. 2400 (DOI: https://doi.org/10.3390/ijerph15112400).

Defra, 2014, *Environmental Noise: Valuing impacts on: sleep disturbance, annoyance, hypertension, productivity and quiet*., Department for Environmental Food & Rural Affairs informed by the Interdepartmental Group on Costs and Benefits Noise Subject Group.

Defra, 2019, 'Defra OGC Preview', Department for Environment, Food and Rural Affairs (https://environment.data.gov.uk/DefraDataDownload/?Mode=OGCPreview&mapService=https%3A%2F%2Fenvironment.data.gov.uk%2Fspatialdata%2Froad-noise-lden-england-round-2%2Fwms) accessed 6 August 2019.

Dominoni, D. M., et al., 2016, 'Airport noise predicts song timing of European birds', *Ecology and Evolution* 6(17), pp. 6151-6159 (DOI: https://doi.org/10.1002/ece3.2357).

Dreger, S., et al., 2019, 'Social inequalities in environmental noise exposure: a review of evidence in the WHO European region', *International Journal of Environmental Research and Public Health* 16(6) (DOI: https://doi.org/10.3390/ijerph16061011).

EASA, et al., 2016, *European aviation environmental report 2016*, European Aviation Safety Agency (EASA), Cologne, Germany (https://easa.europa.eu/newsroom-and-events/news/european-aviation-environmental-report).

EASA, et al., 2019, *European aviation environmental report 2019*, European Union Aviation Safety Agency, Cologne, Germany (https://www.easa.europa.eu/eaer/system/files/usr_uploaded/219473_EASA_EAER_2019_WEB_HI-RES_190311.pdf) accessed 8 September 2019.

EC, 2000, *The noise policy of the European Union*, Office for Official Publications of the European Communities, Luxembourg (http://www.moa.gov.cy/moa/environment/environmentnew.nsf/69D658BCCDE2FDB5C2258041002D61F5/$file/%CE%9Doise%20brochure.pdf) accessed 7 December 2018.

EC, 2008, DIRECTIVE 2008/56/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).

EC, 2011, White Paper — Roadmap to a single European transport area: towards a competitive and resource efficient transport system (COM(2011) 144 final).

EC, 2013, 'Europe's Seaports 2030: Challenges Ahead', European Commission (https://ec.europa.eu/commission/presscorner/detail/en/MEMO_13_448) accessed 15 January 2020.

EC, 2016a, *EU reference scenario 2016 — energy, transport and GHG emissions* — trends to 2050, Publications Office of the European Union, Luxembourg (https://ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf) accessed 10 April 2019.

EC, 2016b, 'Good environmental status — Energy incl. underwater noise' (http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-11/index_en.htm) accessed 22 July 2019.

EC, 2016c, *Links between noise and air pollution and socioeconomic status*, In-depth Report 13, Publications Office of the European Union, Luxembourg (http://dx.publications.europa.eu/10.2779/200217) accessed 24 June 2019.

EC, 2017a, *Noise abatement approaches*, Science for Environment Policy No 17, Publications Office of the European Union, Luxembourg (https://ec.europa.eu/environment/integration/research/newsalert/pdf/

noise_abatement_approaches_FB17_en.pdf) accessed 8 February 2019.

EC, 2017b, Report from the Commission to the European Parliament and the Council on the implementation of the Environmental Noise Directive in accordance with Article 11 of Directive 2002/49/EC (COM(2017) 151 final).

EC, 2019, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions — Environmental Implementation Review 2019: a Europe that protects its citizens and enhances their quality of life (COM(2019) 149 final).

Ecoplan, 2019, *Auswirkungen des Verkehrslärms auf die Gesundheit — Berechnung von DALY für die Schweiz*, Bundesamt für Umwelt.

EEA, 2010, *Good practice guide on noise exposure and potential health effects*, EEA Technical Report No 11/2010, European Environment Agency (https://www.eea.europa.eu/publications/good-practice-guide-on-noise) accessed 14 June 2019.

EEA, 2014a, *Good practice guide on quiet areas*, EEA Technical Report No 4/2014, European Environment Agency.

EEA, 2014b, *Noise in Europe 2014*, EEA Report No 10/2014, European Environment Agency (http://www.eea.europa.eu/publications/noise-in-europe-2014) accessed 20 July 2019.

EEA, 2016, *Quiet areas in Europe — the environment unaffected by noise pollution*, EEA Report No 14/2016, European Environment Agency (https://www.eea.europa.eu/publications/quiet-areas-in-europe) accessed 5 August 2019.

EEA, 2018a, 'Electric vehicles as a proportion of the total fleet', European Environment Agency (https://www.eea.europa.eu/data-and-maps/indicators/proportion-of-vehicle-fleet-meeting-4/assessment-2) accessed 20 July 2019.

EEA, 2018b, *Electric vehicles from life cycle and circular economy perspectives* — TERM 2018, EEA Report No 13/2018, European Environment Agency (https://www.eea.europa.eu/publications/electric-vehicles-from-life-cycle) accessed 15 October 2019.

EEA, 2018c, *Unequal exposure and unequal impacts: social vulnerability to air pollution, noise and extreme temperatures in Europe*, EEA Report No 22/2018, European Environment Agency.

EEA, 2019a, 'Copernicus Land Monitoring Service — Corine Land Cover', European Environment Agency (https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-corine) accessed 18 July 2019.

EEA, 2019b, *Europe's urban air quality — re-assessing implementation challenges in cities*, EEA Report No 24/2018 (https://www.eea.europa.eu/publications/europes-urban-air-quality) accessed 1 August 2019.

EEA, 2019c, 'Exposure of Europe's population to environmental noise', European Environment Agency (https://www.eea.europa.eu/data-and-maps/indicators/exposure-to-and-annoyance-by-2/assessment-4) accessed 10 January 2020.

EEA, 2019d, 'Reported data on noise exposure covered by Directive 2002/49/EC', European Environment Agency (https://www.eea.europa.eu/data-and-maps/data/data-on-noise-exposure-7) accessed 11 January 2020.

EMODnet, 2019, 'EU Vessel density map Detailed method', European Marine Observation and Data Network (EMODnet) (https://www.emodnet-humanactivities.eu/documents/Vessel%20density%20maps_method_v1.5.pdf) accessed 20 January 2020.

ERA, 2018, Recommendation No 006REC1072-1 of the European Union Agency for Railways on the amendment of Commission Regulation (EU) No 1299/2014 on the technical specifications for interoperability relating to the 'infrastructure' subsystem of the rail system in the European Union, Commission Regulation (EU) No 1301/2014 on the technical specifications for interoperability relating to the 'energy' subsystem of the rail system in the European Union and Commission Regulation (EU) No 1304/2014 on the technical specification for interoperability relating to the subsystem 'rolling stock — noise' amending Decision 2008/232/EC and repealing Decision 2011/229/EU (European Union Agency For Railways, Valenciennes).

Eriksson, C. and Pershagen, G., 2018, *Biological mechanisms related to cardiovascular and metabolic effects by environmental noise (2018)*, WHO Regional Office for Europe, Copenhagen (http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2018/biological-mechanisms-related-to-cardiovascular-and-metabolic-effects-by-environmental-noise) accessed 14 June 2019.

ETC/ACM, 2018, *Implications of environmental noise on health and wellbeing in Europe*, Eionet Report ETC/ACM No 2018/10, European Topic Centre on Air Pollution and Climate Change Mitigation (https://acm.eionet.europa.eu/reports/EIONET_Rep_ETCACM_2018_10_HealthImplicationsNoise) accessed 3 April 2019.

ETC/ATNI, 2019a, 'ETC/ATNI Report 3/2019: Noise exposure scenarios in 2020 and 2030 outlooks for EU 28 — Eionet Portal' (https://www.eionet.europa.eu/etcs/etc-atni/products/etc-atni-reports/etc-atni-report-3-2019-noise-exposure-scenarios-in-2020-and-2030-outlooks-for-eu-28) accessed 21 July 2019.

ETC/ATNI, 2019b, *Noise indicators under the Environmental Noise Directive. Methodology for estimating missing data*, Eionet Report ETC/ATNI No 1/2019, European Topic Centre on Air Pollution, Transport, Noise and Industrial Pollution (https://www.eionet.europa.eu/etcs/etc-atni/products/etc-atni-reports/noise-indicators-under-the-environmental-noise-directive-methodology-for-estimating-missing-data) accessed 21 July 2019.

ETC/ATNI, 2019c, *Status of quiet areas in European urban agglomerations*, Eionet Report ETC/ATNI No 10/2019, European Topic Centre on Air Pollution, Transport, Noise and Industrial Pollution (https://www.eionet.europa.eu/etcs/etc-atni/products/etc-atni-reports/etc-atni-report-10-2019-status-of-quiet-areas-in-european-urban-agglomerations) accessed 7 February 2020.

ETC/ATNI, 2019d, *Noise Action Plans. Managing exposure to noise in Europe*, No ETC/ATNI Report No 8/2019 (https://www.eionet.europa.eu/etcs/etc-atni/products/etc-atni-reports/etc-atni-report-8-2019-noise-action-plans-managing-exposure-to-noise-in-europe) accessed 7 February 2020.

ETC/ICM, 2019, *Pressures and their effects upon Europe's marine environment*, No Eionet Report ETC/ICM No 4/2019, European Topic Centre for Inland, Coastal and Marine Waters (https://www.eionet.europa.eu/etcs/etc-icm/products/etc-icm-report-4-2019-multiple-pressures-and-their-combined-effects-in-europes-seas) accessed 7 February 2020.

EU, 1992, Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (OJ L 206, 22.7.1992, p. 7-50).

EU, 2002, Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise (OJ L 189, 18.7.2002, p. 12-25).

EU, 2009, Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (OJ L 20, 26.1.2010, p. 7-25).

EU, 2013, Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet' (OJ L 354, 28.12.2013, p. 171-200).

EU, 2014, Regulation (EU) No 598/2014 of the European Parliament and of the Council of 16 April 2014 on the establishment of rules and procedures with regard to the introduction of noise-related operating restrictions at Union airports within a Balanced Approach and repealing Directive 2002/30/EC (OJ L 173, 12.6.2014, p. 65-78).

EU, 2019a, Commission Implementing Regulation (EU) 2019/774 of 16 May 2019 amending Regulation (EU) No 1304/2014 as regards application of the technical specification for interoperability relating to the subsystem 'rolling stock — noise' to the existing freight wagons (OJ L 1391, 27.5.2019, p. 89-102).

EU, 2019b, Regulation (EU) 2019/1010 of the European Parliament and of the Council of 5 June 2019 on the alignment of reporting obligations in the field of legislation related to the environment, and amending Regulations (EC) No 166/2006 and (EU) No 995/2010 of the European Parliament and of the Council, Directives 2002/49/EC, 2004/35/EC, 2007/2/EC, 2009/147/EC and 2010/63/EU of the European Parliament and of the Council, Council Regulations (EC) No 338/97 and (EC) No 2173/2005, and Council Directive 86/278/EEC (OJ L 170, 25.06.2019, p. 115-127).

Fiebig, A., 2012, 'Scooters: Noise of electric and combustion powered scooters. PTW noise levels, resulting annoyance and potential for reduction', presentation given at: CityHush Training Workshop, Stockholm, 11 December 2012.

Foraster, M., et al., 2016, 'Long-term transportation noise annoyance is associated with subsequent lower levels of physical activity', *Environment International* 91, pp. 341-349 (DOI: https://doi.org/10.1016/j.envint.2016.03.011).

Francis, C. D. and Barber, J. R., 2013, 'A framework for understanding noise impacts on wildlife: an urgent conservation priority', *Frontiers in Ecology and the Environment* 11(6), pp. 305-313 (DOI: https://doi.org/10.1890/120183).

Gate 21, 2019, 'Miljøskærm', Demonstrationsprojekt i Silent City (https://www.gate21.dk/silentcity/miljoeskaerm/) accessed 28 October 2019.

Gentry, K. E., et al., 2018, 'Evidence of suboscine song plasticity in response to traffic noise fluctuations and temporary road closures', *Bioacoustics* 27(2), pp. 165-181 (DOI: https://doi.org/10.1080/09524622.2017.1303645).

Geofabrik, 2019, 'Open street maps dataset' (http://download.geofabrik.de/europe/) accessed 18 July 2019.

Guski, R., 1999, 'Personal and social variables as co-determinants of noise annoyance', *Noise and Health* 1(3), p. 45.

Guski, R., et al., 2017, 'WHO environmental noise guidelines for the European region: a systematic review on environmental noise and annoyance', *International Journal of Environmental Research and Public Health* 14(12), p. 1539 (DOI: https://doi.org/10.3390/ijerph14121539).

Halonen, J. I., et al., 2015, 'Road traffic noise is associated with increased cardiovascular morbidity and mortality and all-cause mortality in London', *European Heart Journal* 36(39), pp. 2653-2661 (DOI: https://doi.org/10.1093/eurheartj/ehv216).

Hänninen, O., et al., 2014, 'Environmental burden of disease in Europe: assessing nine risk factors in six countries', *Environmental Health Perspectives* 122(5), pp. 439-446 (DOI: https://doi.org/10.1289/ehp.1206154).

Health Canada, 2017, *Guidance for evaluating human health impacts in environmental assessment: noise*, Health Canada, Ottawa (http://publications.gc.ca/site/eng/9.832514/publication.html) accessed 14 June 2019.

Health Council of the Netherlands, 2006, *Quiet areas and health — advisory report — the Health Council of the Netherlands*, Health Council of the Netherlands, The Hague (https://www.healthcouncil.nl/documents/advisory-reports/2006/07/04/quiet-areas-and-health) accessed 27 October 2019.

Heathrow Airport Limited, 2013, *A quieter Heathrow*, Heathrow Airport Limited (http://www.sasig.org.uk/wp-content/uploads/2013/05/2013.05.30_A_Qtr_Heathrow.pdf).

Hegewald, J., et al., 2017, 'Breast cancer and exposure to aircraft, road, and railway-noise: a case-control study based on health insurance records', *Scandinavian Journal of Work, Environment & Health* 43(6), pp. 509-518 (DOI: https://doi.org/10.5271/sjweh.3665).

HELCOM, 2018, *State of the Baltic Sea — second Helcom holistic assessment 2011–2016*, Baltic Marine Environment Protection Commission — Helsinki Commission (http://stateofthebalticsea.helcom.fi/) accessed 8 August 2019.

HELCOM, 2019, *Noise sensitivity of animals in the Baltic Sea*, Underwater noise No Baltic Sea Environment Proceedings 167, Baltic Marine Environment Protection Commission (http://www.helcom.fi/Lists/Publications/BSEP167.pdf).

Helldin, J. O., et al., 2013, 'Assessment of traffic noise impact in important bird sites in Sweden — a practical method for the regional scale', *Oecologia Australis* 17(1), pp. 48-62 (DOI: https://doi.org/10.4257/oeco.2013.1701.05).

ICES, 2016, 'Impulsive Noise Register', Impulsive Noise Register (https://underwaternoise.ices.dk/map.aspx) accessed 22 January 2020.

IHME, 2018, *Findings from the global burden of disease study 2017*, Institute for Health Metrics and Evaluation, Seattle, WA (http://www.healthdata.org/sites/default/files/files/policy_report/2019/GBD_2017_Booklet.pdf) accessed 10 November 2019.

International Health Conference, 2002, 'Constitution of the World Health Organization. 1946.', Bulletin of the World Health Organization, 2002.

Jarosińska, D., et al., 2018, 'Development of the WHO environmental noise guidelines for the European region: an introduction', *International Journal of Environmental Research and Public Health* 15(4) (DOI: https://doi.org/10.3390/ijerph15040813).

JRC, 2014, 'OUTPUT — Population distribution (LUISA Platform REF2014)', European Commission — Joint Research Centre (http://data.europa.eu/89h/jrc-luisa-population-ref-2014) accessed 12 July 2019.

JRC, 2016, 'GHS population grid, derived from Eurostat census data (2011) and ESM 2016', EU Open Data Portal (https://data.europa.eu/euodp/en/data/dataset/jrc-ghsl-ghs_pop_eurostat_europe_r2016a) accessed 18 July 2019.

van Kamp, I., 2018, *Study on methodology to perform environmental noise and health assessment*, RIVM Report No 2018-0121, National Institute for Public Health and the Environment (Netherlands) (https://www.rivm.nl/bibliotheek/rapporten/2018-0121.pdf).

Kareklas, K., et al., 2019, 'Signal complexity communicates aggressive intent during contests, but the process is disrupted by noise', *Biology Letters*

15(4), p. 20180841 (DOI: https://doi.org/10.1098/rsbl.2018.0841).

van Kempen, E. E. M. M., 2008, Transportation noise exposure and children's health and cognition, Dissertation (http://dspace.library.uu.nl/handle/1874/25891) accessed 14 January 2020, Utrecht University.

van Kempen, E., et al., 2018, 'WHO environmental noise guidelines for the European region: a systematic review on environmental noise and cardiovascular and metabolic effects: a summary', *International Journal of Environmental Research and Public Health* 15(2), p. 379 (DOI: https://doi.org/10.3390/ijerph15020379).

Kleist, N. J., et al., 2018, 'Chronic anthropogenic noise disrupts glucocorticoid signaling and has multiple effects on fitness in an avian community', *Proceedings of the National Academy of Sciences* 115(4), pp. E648-E657 (DOI: https://doi.org/10.1073/pnas.1709200115).

Kok, A. and van Beek, A., 2019, *Amendments for Cnossos-EU, description of issues and proposed solutions*, RIVM Letter Report No 2019-0023, National Institute for Public Health and the Environment (Netherlands).

Kopsch, F., 2016, 'The cost of aircraft noise — does it differ from road noise? A meta-analysis', *Journal of Air Transport Management 57*, pp. 138-142 (DOI: https://doi.org/10.1016/j.jairtraman.2016.05.011).

Kunc, H. P. and Schmidt, R., 2019, 'The effects of anthropogenic noise on animals: a meta-analysis', *Biology Letters* 15(11), p. 20190649 (DOI: 10.1098/rsbl.2019.0649).

Laib, F. and Schmidt, J. A., 2019, 'Acoustic Vehicle Alerting Systems (AVAS) of electric cars and its possible influence on urban soundscape', conference paper presented at: 23rd International Congress on Acoustics, Aachen, Germany, 9 September 2019.

Maglio, A., et al., 2016, 'Overview of the Noise Hotspots in the Accobams Area: Part I – Mediterranean Sea', conference paper presented at: Sixth Meeting of the Parties to ACCOBAMS, Monaco, 2016.

Manvell, D., et al., 2004, 'SADMAM — combining measurements and calculations to map noise in Madrid', conference paper presented at: 33rd International Congress and Exposition on Noise Control Engineering, Prague, Czechia, 22 August 2004.

Marks, A. and Griefahn, B., 2007, 'Associations between noise sensitivity and sleep, subjectively evaluated sleep quality, annoyance, and performance after exposure to nocturnal traffic noise', *Noise and Health* 9(34), pp. 1-7 (DOI: 10.4103/1463-1741.34698).

Marquis-Favre, C., et al., 2005, 'Noise and its effects — a review on qualitative aspects of sound. Part II: noise and annoyance', *Acta Acustica united with Acustica* 91(4).

Matsinos, Y. G., et al., 2017, 'Identifying the quiet areas of a small urban setting: the case of Mytilene', *Global NEST Journal* 19(4), pp. 674-681.

McClure, C. J. W., et al., 2013, 'An experimental investigation into the effects of traffic noise on distributions of birds: avoiding the phantom road', *Proceedings of the Royal Society B: Biological Sciences* 280(1773), p. 20132290 (DOI: https://doi.org/10.1098/rspb.2013.2290).

Miedema, H. M. E. and Vos, H., 2004, 'Noise annoyance from stationary sources: Relationships with exposure metric day–evening–night level (DENL) and their confidence intervals', *The Journal of the Acoustical Society of America* 116(1), pp. 334-343 (DOI: 10.1121/1.1755241).

Miedema, H. M. E. and Vos, H., 2007, 'Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies', Behavioral Sleep Medicine 5(1), pp. 1-20 (DOI: 10.1207/s15402010bsm0501_1).

Miedema, H. M. and Oudshoorn, C. G., 2001, 'Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals', *Environmental Health Perspectives* 109(4), pp. 409-416.

Mitrus, C. and Zbyryt, A., 2018, 'Reducing avian mortality from noise barrier collisions along an urban roadway', *Urban Ecosystems* 21(2), pp. 351-356 (DOI: https://doi.org/10.1007/s11252-017-0717-7).

Muirhead, M., 2015, *Future potential traffic scenarios*, CEDR Transnational Research Programme: Call 2012 No Deliverable 4.2, Developing Innovative Solutions for Traffic Noise Control in Europe (DISTANCE) (https://www.cedr.eu/download/other_public_files/research_programme/call_2012/road_noise/distance/DISTANCE-TRL-D42-V01-15072015-Future-potential-traffic-scenarios.pdf) accessed 7 July 2019.

Murphy, E. and King, Eoi A., 2014, *Environmental noise pollution: noise mapping, public health, and policy*, Elsevier, Burlington, MA; San Diego, CA.

Nieuwenhuijsen, M. J., et al., 2017, 'WHO environmental noise guidelines for the European region: a systematic review on environmental noise and adverse birth outcomes', *International Journal of Environmental Research and Public Health* 14(10) (DOI: https://doi.org/10.3390/ijerph14101252).

Orban, E., et al., 2016, 'Residential road traffic noise and high depressive symptoms after five years of follow-up: results from the Heinz Nixdorf Recall Study', *Environmental Health Perspectives* 124(5), pp. 578-585 (DOI: https://doi.org/10.1289/ehp.1409400).

Payne, S. R. and Bruce, N., 2019, 'Exploring the relationship between urban quiet areas and perceived restorative benefits', *International Journal of Environmental Research and Public Health* 16(9), p. 1611 (DOI: https://doi.org/10.3390/ijerph16091611).

Peeters, B. and van Blokland, G., 2018, *Decision and cost/benefit methods for noise abatement measures in Europe*, No M+P.BAFU.15.02.1, European Network of the Heads of Environmental Protection Agencies (https://www.mp.nl/sites/all/files/publicaties/rBAFU.15.02.1.rev6%20-%20decision%20and%20cost-benefit%20methods%20%28final%29.pdf) accessed 8 March 2019.

Peeters, B. and Nusselder, R., 2019, *Overview of critical noise values in the European Region*, No M+P.BAFU.19.01.1, European Network of the Heads of Environmental Protection Agencies.

Peris, E., et al., 2019, 'Assessment of quiet areas in Europe', conference paper presented at: 23rd International Congress on Acoustics, Aachen, Germany, 2019.

Recio, A., et al., 2016, 'Road traffic noise effects on cardiovascular, respiratory, and metabolic health: an integrative model of biological mechanisms', *Environmental Research* 146, pp. 359-370 (DOI: https://doi.org/10.1016/j.envres.2015.12.036).

RIVM, 2010, *Effect of electric cars on traffic noise and safety*, Letter Report No 680300009, National Institute for Public Health and the Environment (Netherlands) (https://www.rivm.nl/bibliotheek/rapporten/680300009.html) accessed 9 August 2019.

Roswall, N., et al., 2017, 'Residential exposure to traffic noise and leisure-time sports — a population-based study', *International Journal of Hygiene and Environmental Health* 220(6), pp. 1006-1013 (DOI: https://doi.org/10.1016/j.ijheh.2017.05.010).

Roswall, N., et al., 2018, 'Associations between residential traffic noise exposure and smoking habits and alcohol consumption — a population-based study', *Environmental Pollution (Barking, Essex: 1987)* 236, pp. 983-991 (DOI: 10.1016/j.envpol.2017.10.093).

Sallis, J. F., et al., 2016, 'Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study', *The Lancet* 387(10034), pp. 2207-2217 (DOI: https://doi.org/10.1016/S0140-6736(15)01284-2).

Salomons, E., et al., 2013, 'Quiet places in cities', QSIDE (http://www.qside.se/proj/pub/QSIDE_Action5_Quiet_places_website.pdf) accessed 4 April 2019.

Shannon, G., et al., 2016, 'A synthesis of two decades of research documenting the effects of noise on wildlife', *Biological Reviews* 91(4), pp. 982-1005 (DOI: https://doi.org/10.1111/brv.12207).

Shepherd, D., et al., 2013, 'Do quiet areas afford greater health-related quality of life than noisy areas?', *International Journal of Environmental Research and Public Health* 10(4), pp. 1284-1303 (DOI: https://doi.org/10.3390/ijerph10041284).

Slabbekoorn, H. and Peet, M., 2003, 'Birds sing at a higher pitch in urban noise', *Nature* 424(6946), p. 267 (DOI: https://doi.org/10.1038/424267a).

Sørensen, M., et al., 2014, 'Exposure to road traffic and railway noise and postmenopausal breast cancer: a cohort study', *International Journal of Cancer* 134(11), pp. 2691-2698 (DOI: https://doi.org/10.1002/ijc.28592).

SPW Mobility and Infrastructures, 2017, 'Management of noise barriers to avoid problems in the future', Department of technical expertise Hydraulics and Environment - General Directoreate of roads and buildings - SPW (https://www.cedr.eu/download/other_public_files/2017_road__traffic_noise_symposium/2-4-Marcocci-Sebastien-Management-of-noise-barriers.pdf) accessed 20 September 2019.

Stahlfest, R., et al., 2015, *Noise from electric vehicles — measurements*, Vejdirektoratet (https://vejdirektoratet.dk/side/noise-electric-vehicles-0) accessed 12 July 2019.

Stansfeld, S. A., 1992, 'Noise, noise sensitivity and psychiatric disorder: epidemiological and psychophysiological studies', *Psychological Medicine. Monograph Supplement* 22, pp. 1-44.

Stansfeld, S. A., 2015, 'Noise effects on health in the context of air pollution exposure', *International Journal of Environmental Research and Public Health* 12(10), pp. 12735-12760 (DOI: https://doi.org/10.3390/ijerph121012735).

Summers, P. D., et al., 2011, 'Are the negative effects of roads on breeding birds caused by traffic noise?', *Journal of Applied Ecology* 48(6), pp. 1527-1534 (DOI: 10.1111/j.1365-2664.2011.02041.x).

TG Noise, 2019, *Towards thresholds for underwater noise Common approaches for interpretation of data obtained in (Joint) Monitoring Programmes*, Technical Report No GES_22-2019-18, 22nd Meeting of the Marine Strategy Coordination Group (WG GES) -, Brussels.

Tobias, A., et al., 2014, 'Does traffic noise influence respiratory mortality?', *European Respiratory Journal* 44(3), pp. 797-799 (DOI: https://doi.org/10.1183/09031936.00176213).

Tonne, C., et al., 2018, 'Socioeconomic and ethnic inequalities in exposure to air and noise pollution in London', *Environment International* 115, pp. 170-179 (DOI: https://doi.org/10.1016/j.envint.2018.03.023).

Topsonic, 2016, 'Fluglärmüberwachung — Online — Flughafen München', TraVis (https://travis-web01.munich-airport.de/data/travis.php?lang=en) accessed 3 August 2019.

Trafikverket, 2014, Buller och vibrationer från trafik på väg och järnväg (TDOK 2014:1021).

Trafikverket, 2015, Riktlinje landskap (TDOK 2015:0323).

Triekol, 2017, 'Triekol III Applied Road and Rail Ecology Project plan 2017–2022', Applied Road and Rail Ecology (http://media.triekol.se/2018/01/TRIEKOL-Projektplan-delprojekt-2017-07-12.pdf) accessed 10 November 2019.

Troïanowski, M., et al., 2017, 'Effects of traffic noise on tree frog stress levels, immunity, and color signaling', *Conservation Biology* 31(5), pp. 1132-1140 (DOI: 10.1111/cobi.12893).

Trojanek, R., et al., 2017, 'The impact of aircraft noise on housing prices in Poznan', *Sustainability* 9(11), pp. 1-16.

UBA-DE, 2013, *Kurzfristig kaum Lärmminderung durch Elektroautos*, Umwelt Bundesamt (https://www.umweltbundesamt.de/dokument/kurzfristig-kaum-laermminderung-durch-elektroautos) accessed 12 July 2019.

UWE, 2013, 'Science for environment policy future brief: underwater noise', European Commission DG Environment (https://ec.europa.eu/environment/integration/research/newsalert/pdf/FB7_en.pdf) accessed 10 November 2019.

VITO, 2003, K*wantificering van gezondheidsrisico's aan de hand van DALYs en externe gezondheidskosten (Quantification of health risks using DALYs and external health costs (in Dutch))*, No MIRA/2003/02, VITO (https://docplayer.nl/12281058-Kwantificering-van-gezondheidsrisico-s-aan-de-hand-van-dalys-en-externe-gezondheidskosten.html) accessed 20 June 2019.

Weilgart, L., 2018, *The impact of ocean noise pollution on fish and invertebrates*, OceanCare and Dalhousie University (https://www.oceancare.org/wp-content/uploads/2017/10/OceanNoise_FishInvertebrates_May2018.pdf) accessed 8 August 2019.

WHO, 2018, *Environmental noise guidelines for the European region*, WHO Regional Office for Europe, Copenhagen (http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2018/environmental-noise-guidelines-for-the-european-region-2018) accessed 7 December 2018.

WHO, 2019, *Environmental health inequalities in Europe. Second assessment report* (2019), WHO Regional Office for Europe, Copenhagen.

WHO Europe, 2009, *WHO night noise guidelines for Europe*, WHO Regional Office for Europe, Copenhagen (http://www.euro.who.int/en/health-topics/environment-and-health/noise/policy/who-night-noise-guidelines-for-europe) accessed 14 June 2019.

WHO and JRC, 2011, *Burden of disease from environmental noise — quantification of healthy life years lost in Europe*, World Health Organization (http://www.who.int/quantifying_ehimpacts/publications/e94888/en/) accessed 5 May 2014.

Annex 1 Key legislation regulating noise at source in the EU

Noise source	Related EU legislation
Roads	• Directive 97/24/EC on certain components and characteristics of two- or three-wheel motor vehicles • Directive 2001/43/EC amending Council Directive 92/23/EEC relating to tyres for motor vehicles and their trailers and to their fitting • Regulation (EC) No 661/2009 concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units • Regulation (EC) No 661/2009 of the European Parliament and of the Council of 13 July 2009 concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefore • Regulation (EC) No 1222/2009 of the European Parliament and of the Council of 25 November 2009 on the labelling of tyres with respect to fuel efficiency and other essential parameters • Regulation (EU) 168/2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles • Regulation (EU) 540/2014 on the sound level of motor vehicles and of replacement silencing systems, and amending Directive 2007/46/EC and repealing Directive 70/157/EEC
Railways	• Commission Decision 2002/735/EC concerning the technical specification for interoperability relating to the rolling stock subsystem of the trans-European high-speed rail system referred to in Article 6(1) of Directive 96/48/EC • Commission Decision 2002/732/EC relating to technical specification for interoperability relating to high speed railway infrastructures • Directive 2008/57/EC on the interoperability of the rail system within the Community • COM(2008)432 Communication from the Commission to the European Parliament and the Council — Rail noise abatement measures addressing the existing fleet (rail) • Commission Decision 2011/229/EU of concerning the technical specifications of interoperability relating to the subsystem 'rolling stock-noise' of the trans-European conventional rail system
Aircraft	• Directive 89/629/EEC of 4 December 1989 on the limitation of noise emission from civil subsonic jet aeroplanes • Directive 2006/93/EC on the regulation of the operation of aeroplanes covered by the Convention on International Civil Aviation • Regulation 216/2008/EC on common rules in the field of civil aviation • Regulation (EU) No 598/2014 of the European Parliament and of the Council of 16 April 2014 on the establishment of rules and procedures with regard to the introduction of noise-related operating restrictions at Union airports within a Balanced Approach and repealing Directive 2002/30/EC
Industry	• Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (Recast)
Outdoor equipment	• Directive 2000/14/EC on the approximation of the laws of the Member States relating to the noise emission in the environment by equipment for use outdoors

Annex 2 Data completeness by country

Table A2.1 Data completeness of L_{den} values in 2017 by country

Country	Completeness of reported L_{den} value (%)							
	Inside urban areas				Outside urban areas			Total
	Road	Rail	Air	Industry	Road	Rail	Air	**All**
Austria	100	100	100	100	100	100	100	**100**
Belgium	73.9	67.1	94.8	47.9	100	100	0 ([a])	**82.7**
Bulgaria	94.6	99.1	100	88.9	100		0	**79.2**
Croatia	100	100	100	100	100	100		**100**
Cyprus	0	0	0	0	0			**0**
Czechia	100	100	100	100	100	100	100	**100**
Denmark	100	0	100	50	100	100	90	**98.0**
Estonia	100	100	100	100	100			**100**
Finland	100	100	24.2	94.4	100	100	100	**99.6**
France	43.6	49.7	35.3	8.7	100	100	0	**62.4**
Germany	94.3	100	100	98.7	100	100	100	**97.9**
Greece	0	0	0	0	0	0	0	**0**
Hungary	100	100	100	100	100	100	100	**100**
Iceland	100		100	100			100	**100**
Ireland	100	100	100		100	100	100	**100**
Italy	0	0	0	0	0	100	0 ([a])	**10.6**
Latvia	100	100	100	100	100	100	100	**100**
Liechtenstein					0			**0**
Lithuania	100	100	100	100	100	100		**100**
Luxembourg	100	100	100		100	100	100	**100**
Malta	100		100	100	100			**100**
Netherlands	100	100	100	100	100	100	100	**100**
Norway	87.2	99.6	64.4	87.5	99.6	100	0	**89.6**
Poland	100	96.8	100	98.0	100	100	100	**99.9**
Portugal	100	100	100	100	90.9	100	100	**95.5**
Romania	9.5	0	0	0	0	0	0 ([a])	**7.0**
Slovakia	0	0	0	0	0	0		**0**
Slovenia	100	100		100	100	100		**100**
Spain	22.3	7.8	0	47.8	24.4	9.5	100	**22.5**
Sweden	100	100	78.4	100	100	100	100	**99.8**
Switzerland	100	100	100	0	100	100	100	**99.6**
United Kingdom	100	100	100	100	100	100	100	**100**
Total	**61.9**	**73.3**	**70.7**	**42.7**	**69.9**	**96.0**	**76.1**	**67.4**

Notes: ([a]) These data were submitted before 1 January 2019, but for technical reasons they were not included in this report.

The completeness was calculated using the following formula: (sum of the reported number of people exposed to L_{den} ≥ 55 dB/sum of the expected number of people exposed to L_{den} ≥ 55 dB) × 100.

Based on data submitted up to 1 January 2019.

Table A2.2 Data completeness of L_{night} values in 2017 by country

Country	Completeness of reported L_{night} value (%)							
	Inside urban areas				Outside urban areas			Total
	Road	Rail	Air	Industry	Road	Rail	Air	All
Austria	100	100	100	100	100	100	100	**100**
Belgium	76.4	65.0	87.7	51.6	100	100	0 ([a])	**84.5**
Bulgaria	94.4	100	100	93.8	100		0	**78.9**
Croatia	100	100	100	100	100	100		**100**
Cyprus	0	0	0	0	0			**0**
Czechia	100	100	100	100	100	100	100	**100**
Denmark	100	0	100	50	100	100	100	**98.1**
Estonia	100	100	100	100	100			**100**
Finland	100	100	40	100	100	100	100	**99.8**
France	44.3	51.4	26.6	7.2	100	100	0	**64.3**
Germany	94.4	100	100	99.5	100	100	100	**98.0**
Greece	0	0	0	0	0	0	0	**0**
Hungary	100	100	100	100	100	100	100	**100**
Iceland	100		100	100			100	**100**
Ireland	100	100	100		100	100	100	**100**
Italy	0	0	0	0	0	100	0 ([a])	**11.9**
Latvia	100	100	100	100	100	100	100	**100**
Liechtenstein					0			**0**
Lithuania	100	100	100	100	100	100		**100**
Luxembourg	100	100	100		100	100	100	**100**
Malta	100		100	100	100			**100**
Netherlands	100	100	100	100	100	100	100	**100**
Norway	87.0	99.7	45.3	75.0	100	100	0	**89.7**
Poland	100	96.1	100	97.4	100	100	100	**99.9**
Portugal	100	100	100	100	90.7	100	100	**95.8**
Romania	8.0	0	0	0	0	0	0 ([a])	**6.4**
Slovakia	0	0	0	0	0	0		**0**
Slovenia	100	100		100	100	100		**100**
Spain	18.6	3.4	0	58.4	22.1	7.2	100	**18.5**
Sweden	100	100	0	100	100	100	100	**99.9**
Switzerland	100	100	100	0	100	100	100	**99.7**
United Kingdom	100	100	100	100	100	100	100	**100**
Total	**58.8**	**73.4**	**71.4**	**52.1**	**67.1**	**96.4**	**82.3**	**65.5**

Notes: ([a]) These data were submitted before 1 January 2019, but for technical reasons they were not included in this report.

The completeness was calculated using the following formula: (sum of the reported number of people exposed to L_{night} ≥ 50 dB/sum of the expected number of people exposed to L_{night} ≥ 50 dB) × 100.

Based on data submitted up to 1 January 2019.

European Environment Agency

Environmental noise in Europe — 2020

2020 — 100 pp. — 21 x 29.7 cm

ISBN 978-92-9480-209-5
doi: 10.2800/686249

TH-AL-20-003-EN-N
doi: 10.2800/686249

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Tel.: +45 33 36 71 00
Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

Publications Office
of the European Union