Qualitative assessment of links between exposure to noise and air pollution and socioeconomic status

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Executive Summary

Introduction (Section 1)

The scope of the work requested under this specific contract is to provide a report/assessment text that may be directly incorporated into EEA's 2018 report exploring the linkages between socioeconomic status (SES) in Europe and exposure to air and noise pollution, as well as to climate-related impacts. More specifically, this report builds on the findings of the 2016 Science for Environment Policy (SEP) report[1] to provide an updated qualitative review of the latest evidence and state of knowledge regarding the role of SES in determining exposure, susceptibility and vulnerability to air pollution and noise, documenting research that explores the multiple factors and drivers that can lie behind these linkages. This review has identified and synthesised evidence from a wide range of sources in response to the objectives set by the EEA and covers evidence relating to at least 18 of the EEA-33 countries. The conclusions presented here explicitly identify where this review confirms, contradicts or adds to the conclusions of the SEP report.

Policy context (Section 2)

As an introduction, to understand the policy context of the subject in Europe, a review of relevant EU environment policies was undertaken to determine the extent to which any mention of social inequality factors has been included. The analysis suggests that while higher-level and longer-term documents within an environmental scope are likely to include references to socioeconomic factors, with some of them also looking at the interplay between social deprivation and exposure, the environmental directives do not integrate these aspects to date.

The SEP report had highlighted that there are multiple ways of defining SES and that different studies use various different indicators. To explore this issue further, a review of historical and current SES proxies used in studies was undertaken. The review revealed similarities and discrepancies in SES proxies throughout their evolution, which was reflected in the broader studies reviewed, demonstrating the difficulties in drawing comparisons and broader applicability from studies based on different SES metrics. . It should be noted that SES proxies do not just vary temporally, however; studies undertaken in different countries will use different indices depending on available metrics.

Update to the SEP report (Section 3)

Changes in global/European trends, spatial scales of impact, types of noise and air pollution, types of health impact and key sources of noise and air pollution were also updated since the publication of the Science for Environment Policy (SEP) report in September 2016. In the relatively short period since the SEP report was prepared a number of key reviews have been published that provide a detailed and comprehensive overview of health impacts and the latest emission trends. In general, these studies show that population exposure to noise pollution is decreasing (in contrast to the SEP report, which indicated that noise was increasing in Europe). Globally, air pollution is increasing but in Europe, despite reducing emissions of most air pollutants, exposure has not decreased by as much. This is largely attributed to continued exceedences of the AAQD limit values, increased population size, an aging population and increased levels of air pollution in low-income and middle-income income countries.

[1] http://ec.europa.eu/science-environment-policy

Spatial scales of exposure to noise and air pollution are complex and relate primarily to urbanisation and direct proximity to source. Different studies reveal different results depending on the spatial scale of assessment, which is often determined by aggregate availability of data. Spatial scales of exposure are further complicated by assessment of personal exposures.

Types and sources of pollutants have not changed significantly with road traffic being the dominant source of both noise and air pollution in urban areas, and agriculture a source of increasing ammonia and nitrates. Rail, aircraft noise and industrial noise are the other key noise sources. Non-exhaust emissions are also a significant source of air pollution, as are non-road traffic sources e.g. rail and shipping. In some areas domestic wood- and other solid fuel-burning is an increasingly problematic source. Localised exposure to emissions from municipal solid waste incineration and waste treatment plants, industrial sources and agricultural emissions are also reported.

The health and well-being endpoints considered for noise exposure assessment were annoyance, sleep disturbance, cognitive performance, diabetes, hypertension, cardiovascular and cerebrovascular disease and mortality, all of which were identified in the SEP report. The assessment of health impacts due to noise should ideally be based on integrating people's perception, sociodemographic factors, residents' lifestyles factors and environmental and territorial context. Ambient air pollution-related premature deaths are attributed to ischaemic heart disease (IHD) and stroke, chronic obstructive pulmonary disease (COPD), acute lower respiratory infections (LRIs) and lung cancer with cardiovascular diseases representing the largest impact of air pollution. Emerging evidence suggests that additional causal associations may exist between $PM_{2.5}$ pollution and several highly prevalent non-communicable diseases, including diabetes, decreased cognitive function, attention-deficit or hyperactivity disorder and autism in children, and neurodegenerative disease, including dementia, in adults.

It is worth noting that exposure to traffic noise and air pollution are intertwined because of their common source, therefore identifying the relative contribution in terms of health impacts can be problematic. This is particularly difficult in studies looking at perceived exposure, where noise may be over-represented due to its more obvious impacts. Furthermore, as existing evidence suggests a possible combined effect of air pollution and noise on health, the established association between air pollution and life satisfaction may partly reflect the synergistic effect of noise.

Impacts of SES on vulnerability to exposure to noise and air pollution (Section 4)

Factors that help to determine the exposure of different SES groups (4.1)

An analysis of the evidence relating to exposure of different socioeconomic groups to noise and air pollution reveals that there are multiple, sometimes interrelated, factors at play, and some inconclusive and contrary evidence to suggest that those in the lowest socioeconomic groups may not always be the most affected, depending on sources and scales of impact. This supports the findings of the SEP report, which highlighted the difficulty in proving causal mechanisms between low SES and exposure due to the inherent complexities. Indeed most studies refer to statistically significant 'associations', but do not categorically claim 'cause and effect'. However, a consistent theme emerging from the disparate studies is that exposure to noise and air pollution appears to be strongly related to urbanisation/population density, with road traffic being the dominant source. Areas worst affected by road traffic (and other urban sources of noise and air pollution) tend to be cheaper in value, thereby attracting those in lower SES groups. However, it is unclear the extent to which cheaper areas also attract more polluting sources or whether the polluting sources devalue an area, although it is likely that, in some areas at least, both aspects play a role. Furthermore, as the SEP report states, there are additional factors, other than cost, that influence where people live, including access to facilities and transport links, which thereby influence people's relative exposure, and may even have positive mental health impacts, e.g. greater opportunities for social interaction.

Reflections on how people of higher incomes can reduce their exposure and increase their resilience to air pollution and/or noise (4.2)

Although low SES is generally more closely related to exposure to noise and air pollution than higher SES, there is little new evidence relating to the ability of more affluent individuals or households to be able to avoid air or noise pollution as suggested in the SEP report. Where it exists, this primarily relates to residential location as a demonstration of their ability to implement 'willingness to pay' behaviour and is most clearly apparent in relation to noise exposure. However, as evidenced by the SEP report and more recent studies reported in this review, some areas with higher noise and air pollution may still be more affluent due to the other benefits of living in those areas increasing the value of properties in these areas. This does not necessarily mean that residents of those areas are more exposed, however, as the SEP report indicates, as individuals that are more affluent may be able to better insulate their homes and may be able to spend more time away from the affected area. However, no additional evidence was found in this review to substantiate that theory.

The role that lifestyle factors and occupation may have in influencing sensitivity and vulnerability, linked to SES (4.3)

Choosing to live in areas with high levels of air and noise pollution, as opposed to being forced to through economic constraints, may be considered a lifestyle choice, assuming residents are cognisant of the trade-offs they are potentially making. Within the limited evidence available, it was identified that while more health-damaging lifestyles may be linked to lower SES, as identified in the SEP report, lifestyle factors may be independently related to exposure and may have an additive effect in terms of health impact. Studies relating to occupational risk factors identified increased health impacts associated with certain professions and anxieties related to job insecurity associated with exposure to traffic-related pollutants.

Evidence of the increased sensitivity and vulnerability of sensitive population groups (i.e. the young and the aging population) to poor air quality and noise (4.4)

As identified in the SEP report and this review, there is strong evidence to suggest that those in low SES groups are more at risk of negative health impacts, although unpicking this from their relative exposure and lifestyle factors may be difficult. This review also examines the particular vulnerability of sensitive population groups, e.g. young children and the elderly, within those low SES groups that may be considered to be subject to the 'quadruple jeopardy' of having (1) low SES, (2) the health impacts commonly associated with low SES, (3) increased exposure to air and noise pollution and (4) the additional susceptibility of being sensitive to the effects of exposure. Although evidence is mixed, the majority of studies reviewed indicate that exposure to air and/or noise pollution in sensitive groups, particularly those with low SES, are more likely to suffer physical and mental health impacts relating to that exposure. Sensitive groups examined in this review are children, including prenatal, teenagers, the elderly and those with existing health conditions.

Evidence of how people of lower socioeconomic status are exposed to combined stressors, in particular in urban environments (4.5)

Most of the reviewed studies demonstrate that people with lower SES tend to live in worse environmental conditions with respect to noise and air pollution, and with lower accessibility to green spaces, although national and regional differences are also observed. This is an outcome of the interaction of multiple factors linked to urbanisation, which also includes increased heat exposure, which can exacerbate the health effects of exposure to air pollution in particular, a situation that is likely to worsen with the intensified Urban Heat Island effect anticipated under climate change scenarios. Living in urban areas therefore brings a complexity of interrelated issues to bear, beyond increased exposure to air and noise pollution. People with lower SES are also subject to increased vulnerabilities and sensitivity, therefore the combination of low SES and exposure to these combined stressors is of additional concern. Spatial correlations between the different environmental hazards also imply that exposures will rarely occur alone. The combined effects of deprivation and environmental exposure are, however, likely to be more complex than additive.

Impacts of socioeconomic status on generation of air pollution (Section 5)

No evidence was found regarding the relationship between SES and generation of noise pollution, however, focusing on air pollution, whilst there is evidence to suggest that more affluent households may be net-polluters, there is also confounding evidence to indicate that the picture is less clear-cut. In England and Wales, higher SES groups tend to own the most vehicles, including the most diesel vehicles, have on average older vehicles and drive the furthest, therefore generating the greatest total emissions and contributing disproportionately to traffic-related pollution. Across Europe, however, lower SES groups are more likely to drive second-hand cars. Lower SES groups are also more likely to use sustainable modes. Most studies have focussed on traffic emission and so further evidence is required to determine the role of SES in generation of air pollution from domestic solid fuel-burning, which is likely to vary depending on the economic status and the dominant fuel type of each country.

Action to reduce exposure to noise and air pollution (Section 6)

Policy measures (6.1)

No conclusive evidence was found of examples of policy measures that have led to a reduction in exposure to noise/air pollution either in or apart from deprived communities. Instead, a selection of evidence is presented which discusses potential and proposed policy measures, including both hard policy measures and soft measures like awareness raising, as well as broader urban initiatives to create more green/blue space. Many current air and noise management strategies are presumed to have a beneficial effect on human health, however further studies are required to establish the link between interventions and long-term health impacts. These studies should cover all sources of air pollution and environmental noise, but, for noise, particularly aircraft and rail sources and for human health outcomes other than annoyance. Further studies are also required to improve the evidence of the effects on different SES subgroups of air and noise interventions. Strategies and measures for implementing environmental justice in municipalities (and municipal planning) are still widely lacking, as evidenced in the policy context (section **Error! Reference source not found.**). When developing Air and Noise Action Plans it would be desirable to integrate social inequalities as a priority. It is recommended that environmental equity issues should be integrated in Environmental Impact Studies, in order to be able to highlight the (re) distributive effects of political decisions.

Case studies (6.2)

Three geographical case studies (one in London, UK, two projects in Germany and one in Bilbao, Spain) have been presented to illustrate examples of policy measures that have been or are being implemented, but for which evidence to evaluate them is not yet available.

1 Introduction

1.1 Introducing the premise for the report

The scope of the work requested under this specific contract is to provide a report/assessment text that may be directly incorporated into EEA's 2018 report, 'Europe's socio-environmental inequalities: linking socio-economic deprivation with environmental hazards', exploring the linkages between socioeconomic status (SES) in Europe and exposure to air and noise pollution, as well as to climate-related impacts. This review thereby complements the quantitative analysis of air pollution, noise and social deprivation being undertaken by Aether, a quantitative analysis of climate hazards and social deprivation being undertaken by the EEA and a report on social vulnerability to climate change in European cities[2] produced by the European Topic Centre on Climate Change impacts, vulnerability and Adaptation.

More specifically, this report builds on the findings of the Science for Environment Policy (SEP) report[3] to provide an updated qualitative review of the latest evidence and state of knowledge regarding the role of SES in determining exposure, susceptibility and vulnerability to air pollution and noise, documenting research that explores the multiple factors and drivers that can lie behind these linkages.

1.2 Background to the issues

Air and noise pollution have many of the same sources, such as heavy industry, aircraft, railways and road vehicles, although there are many more additional sources for air pollution, e.g. energy, household combustion, agriculture. According to the SEP report, research suggests that the social cost of noise and air pollution in the EU — including death and disease — could be nearly €1 trillion (Science for Environment Policy, 2016). The urban population in Europe is increasing and with it the potential for increased exposure to air and noise pollution. In addition, there is a widening disparity between the most and least affluent in society (OECD, 2017) with a body of evidence, presented in both the SEP report and this review, that those households in areas of highest deprivation are increasingly exposed to the highest air and noise pollution. Air pollution and noise pollution have negative health impacts on all socioeconomic groups, rich and poor. However, the risks may not be evenly shared; it is often society's poorest who live and work in the most polluted environments (Science for Environment Policy, 2016). These same people may be more impacted by pollution's damaging effects than more advantaged groups of society. WHO (2012) has presented evidence of significant environmental health inequalities across the European region. An individual's socioeconomic status influences their exposure, their vulnerability, and their resilience in adapting to environmental risks. Furthermore, there is emerging evidence that it is the more affluent households that may be primarily responsible for the generation of heating and traffic-related emissions.

Exposure to air and noise pollution have many demonstrable effects on our health, both physical and mental. These include respiratory health issues (such as asthma), cardiovascular health problems (such as heart disease or stroke), anxiety and sleep disturbance. It seems likely that some groups of society are more affected than others by these health impacts. However, these 'health inequalities' may arise

[2] http://cca.eionet.europa.eu/reports/TP_1-2018
[3] http://ec.europa.eu/science-environment-policy

because of either increased exposure to pollution, or increased sensitivity to pollution, or increased vulnerabilities, or, perhaps most likely, a combination of all three. Health research already shows that people of low SES face a greater risk of heart disease, mental health problems and poor sleep. These are also some of the most commonly studied health impacts of air and noise pollution, which seem also to be exacerbated by greater pollutant exposure.

Research from around the world provides many examples of disadvantaged communities who are exposed to higher levels of air and noise pollution than more advantaged groups. These studies are largely focused on specific regions or cities, and a large number of studies focus on traffic as a pollution source. This is not a universal pattern, however, and the evidence on exposure in European cities is somewhat more mixed. Various studies show that polluted city centre locations are often favoured by affluent groups, for example.

Lower SES is associated with poorer health in a more general sense. Numerous studies have shown increased health effects or deaths in deprived populations associated with noise and air pollution, compared with wealthier populations. Again, studies tend to be carried out in specific regions, cities or even in areas considered hotspots around main sources such as airports or railroad lines, but there are also a few exceptions of studies at national levels. Noise and air pollution contribute to a wide range of factors influencing the health of populations, from aspects of the built environment to individual lifestyle choices. Although their specific contributions may be difficult to measure, ‘multiple risk exposures’ are thought to accumulate in deprived populations, contributing to ‘causal pathways’ towards negative health impacts. These pathways may also involve socioeconomic factors, such as income and education, lifestyle factors, such as diet and exercise (which are linked to socioeconomic factors) and exposure to other kinds of environmental stress.

1.3 Summary of the key findings of the Science for Environment Policy report ‘Links between noise and air pollution and socioeconomic status’

In September 2016, UWE Bristol produced the European Commission Science for Environment Policy (SEP) In-depth Report 13[4].

While the report acknowledged that there are key differentials between SES and risk of effect from air or noise pollution, it also highlighted that there are many inherent complexities. For example, although deprived populations living in areas that are exposed to high levels of pollution, or are exposed over a long duration, experience the worst effects, studies to date (although limited in number) also suggest that more advantaged communities are not as likely to suffer pollution-related health impacts as poorer communities, even where the advantaged communities live in more polluted areas. This potentially means that deprived populations are either more sensitive to the effects of noise and air pollution (e.g. through existing long-term health conditions, or less healthy lifestyles), or that more affluent populations are less vulnerable (e.g. through paying for better healthcare and lifestyle goods). For instance, despite living in a polluted area, wealthier residents may be able to afford better-constructed housing, and they may be more likely to work indoors and use private transport, avoiding negative health impacts.

[4] http://ec.europa.eu/science-environment-policy

The SEP report also highlighted some of the methodological challenges faced by researchers in this field, for example, different studies define SES in different ways and assess exposure and impacts at different scales. Existing research tends to focus on average exposure and impacts at the local or neighbourhood scale, but geographical units of study (i.e. the 'length size' ranging from tens of meters or kilometres) are very various. Overall, very few studies consider the European or global picture. Further studies directly measuring both exposure and health impacts are needed to explore associations between SES and noise and air pollution in Europe, and that longitudinal studies — involving multiple rounds of data collection — are required to understand the long-term consequences of exposure to air and noise pollution, as well as studies investigating the effects of moving between areas with different socioeconomic characteristics and with different levels of exposure to pollution.

Following the findings of the SEP report and based on the latest research, there is therefore a need to update the review based on growing evidence of the interlinkages between exposure to air pollution and noise and SES and to explore some of these complex drivers behind exposure, vulnerability and resilience, building on the recommended areas for further research highlighted in the SEP report.

1.4 Approach and objectives

1.4.1 *Explanation of the contribution of this report*

This report presents the findings of the review undertaken to update and investigate the issues highlighted in the SEP report, reflecting the objectives outlined in section 1.4.2. As an update to the 2016 SEP report, this review has therefore focussed on the most recent literature (primarily 2016-2018), although earlier texts have been included where relevant. The review has covered the policy context (section **Error! Reference source not found.**), including a review of environmental policy (2.2) and a summary of the evolution of SES proxies in studies over the last 25 years (2.3). An update to the SEP report on global and European trends, spatial scales of impact, types of noise and air pollution, types of health impact and key sources of noise and air pollution is presented in section **Error! Reference source not found.**. Section 4 provides an in-depth examination of impacts of SES on vulnerability to exposure to noise and air pollution and section **Error! Reference source not found.** introduces emerging evidence relating to impacts of SES on generation of air pollution. Section **Error! Reference source not found.** focuses on action to reduce exposure to noise and air pollution including a review of policy measures and selected case studies.

The geographical scope of the report captures a broad range of evidence from across EEA member countries, aiming to explore differences in context related to social circumstances, urban structure and environmental quality at the local, national and regional level where appropriate. The report focusses on evidence relating to ambient (outdoor) sources rather than indoor sources and is limited to evidence available as full text in English language. Limitations of the review are presented in section 0.

1.4.2 *Key objectives of the report*

In order to address the need for further synthesis of the evidence, the following objectives were outlined in the tender specifications:

- **Review of qualitative and quantitative studies of the linkages between exposure to noise and air pollution and SES:** Provide an updated summary and review of latest available information, drawn from both scientific and grey literature sources, covering past qualitative and quantitative studies of the linkages between exposure to noise and air pollution and SES. This review should build upon earlier summary publications in this area, specifically the SEP report referred to above. The report should summarise relevant cohort (longitudinal) studies that might provide epidemiological evidence of negative health impacts from noise and air pollution linked to SES; (see section 4);

- **Discussion on the SES impact on exposure and vulnerability:** Provide an expanded discussion on how the modalities of SES impact on exposure and vulnerability on the basis of existing information. This should highlight the various factors that help determine the exposure of different socioeconomic groups. For example, this could include a discussion of the structural dimensions of low quality neighbourhoods that can lead to both increased exposure and increased vulnerability, such as spatial planning, locations next to busy roads, housing conditions, access to transport and access to green/blue spaces and quiet areas. Conversely, reflections on how people on higher incomes can reduce their exposure and increase their resilience to air pollution and/or noise by paying for higher quality housing, health care etc. should be described; (see section 4)
- **Policy measures:** Provide examples, where available, of policy measures that have been implemented and served to reduce exposure to noise and air pollution in deprived communities, achieved through either specific measures or resulting as co-benefits; (see section 6.1);
- **Case studies:** Draw upon case studies from across EEA member countries. (see section 6.2).

In addition, some more general aspects to be included as specific additions within the scope of the report were:

- A discussion of the various approaches used in the literature to **define SES and the dimensions of social deprivation/privilege, as well as an overview of how these dimensions have changed in Europe over the past 20 years** (on the basis of existing assessments where available). This includes a reflection on the approaches set out in the Urban Agenda for the EU, as well as material from the Commission publications “Cities of tomorrow” and “The state of European cities 2016”. To complement this section, EEA provided to the service provider the list of indicators assessed in the quantitative work undertaken by ETC/ACM. (see section 2.3)
- **A description and review of the extent to which any mention of social inequality factors has been included (or not) within relevant EU environment policies**. This addresses the EU’s over-arching environmental objectives as laid out in the 7th Environment Action Programme (7EAP), as well as within thematic legislation addressing air quality, environmental noise, spatial planning aspects etc. The review also captures relevant objectives set out in the Declaration of the sixth Ministerial Conference on Environment and Health and its Annexes. (see section 2.2)
- **A description of the role that lifestyle factors and occupation may have in influencing sensitivity and vulnerability, including a reflection of how these are linked to SES**. Evidence of the increased sensitivity and vulnerability of sensitive population groups (i.e. the young and the aging population) to poor air quality and noise has been summarised. (see section **Error! Reference source not found.**)
- Inclusion of any **new information if possible from studies assessing the contribution that different socioeconomic groups in society make to air pollution** e.g. whether new/larger vehicles drive further and are responsible for more air pollution than older cars; high use of wood-burning for domestic heating/cooking by less wealthy groups of society etc. An objective here may be to complement the discussion of inequity concerning exposure to air pollution with a discussion of inequity in terms of the generation of air pollution. (see section **Error! Reference source not found.**)
- Identify key **knowledge gaps and areas for future research.** (see section 7.2)

1.4.3 *Brief methodology/sources.*

The objectives outlined in section 1.4.2 have been addressed by conducting a review of available scientific and grey literature, including policy documents and research project reports. In brief, the review has sourced evidence from:

- database searches of peer-reviewed papers and reports,
- requests for material from networks/contacts/projects, and
- material sourced by EEA from Eionet National Reference Centres.

The methodological approach is presented in Figure 1. The database search was undertaken in Scopus, using search terms (Appendix 1: Search terms) agreed by the project team relating to:

- (Generation of/Exposure to) Air Pollution
- (Generation of/Exposure to) Noise Pollution
- Socioeconomic status (SES)
- Health impacts/vulnerability

Requests for material were sent to 41 contacts from across Europe and further afield who had published on SES, noise and/or air pollution and health, or who were involved in projects relating to these topics. Responses were received from eight of the contacts providing both published and unpublished material as well as signposting project websites and current studies.

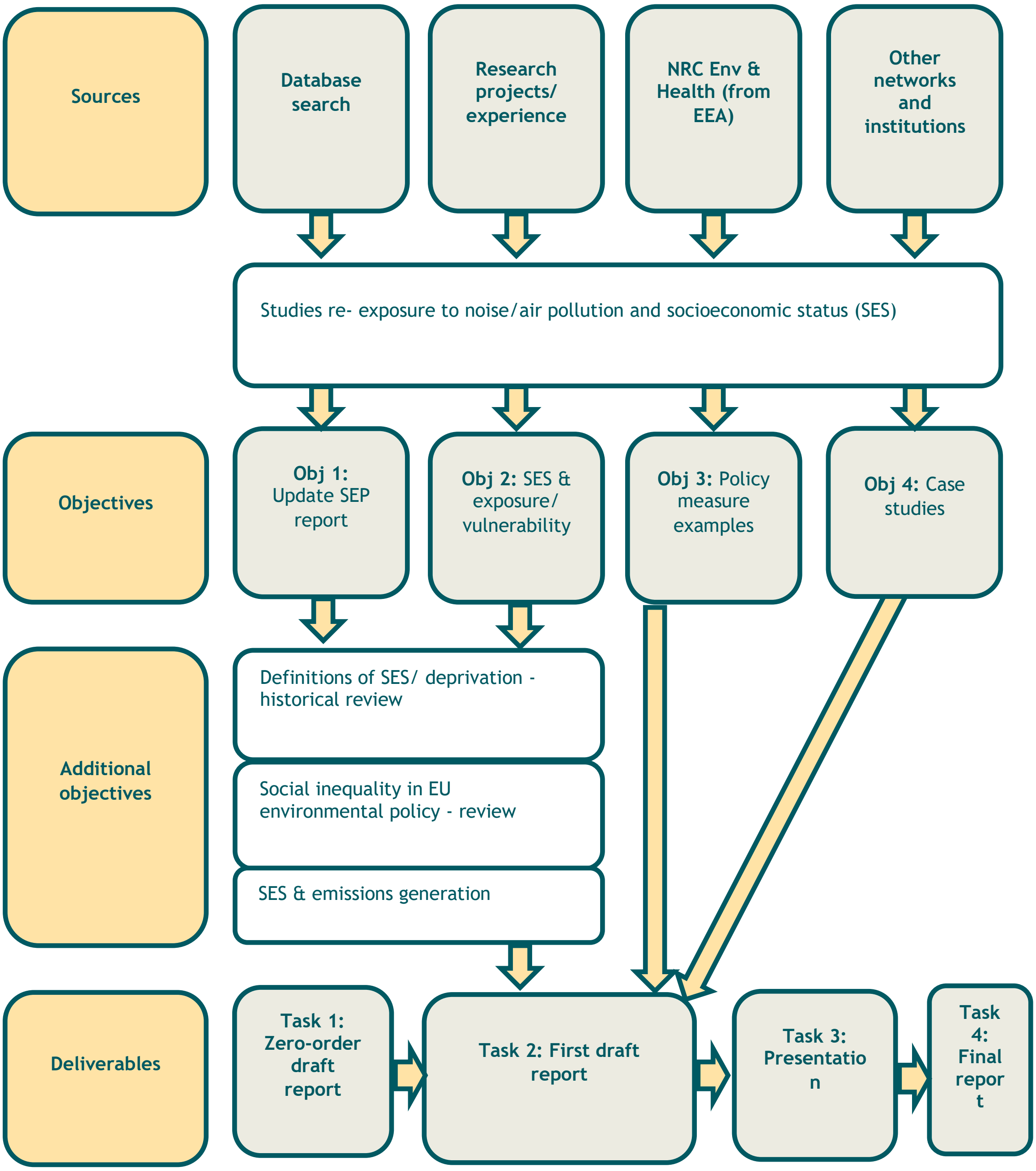
EEA requests for evidence generated responses from eight member countries (Austria, Belgium, France, Germany, Malta, Slovenia, Sweden and Switzerland), helpfully translated to English by the EEA where necessary.

Responsibilities within the project team were divided based on expertise, with UWE taking responsibility for air pollution, UAB leading on noise and RIVM providing assistance and quality assurance support to both on health and SES. The database search was conducted by UWE. Search results relating to SES, health and air pollution were reviewed by UWE and results relating to SES, health and noise were reviewed by UAB. The initial Scopus search generated 2,499 results relating to air and 730 relating to noise. Titles and abstracts were skimmed for relevance by the respective institutions to identify a 'short list' of relevant papers. After deduping, a systematic review of relevant material identified 256 relevant search results relating to air and 150 for noise, covering at least 18 of the EEA-33 countries. UWE also scanned all materials received from contacts and the EEA for relevance and separated these by air and noise for review by the respective institutions. Areas of overlap were also identified and shared between institutions to ensure the respective perspectives were addressed. Synthesis of the evidence was undertaken by UWE and UAB, with UWE, as project lead, drawing it all together.

Limitations of the review

For evidence relating to health studies, review studies were primarily used on advice from experts at RIVM as neither UAB nor UWE teams were sufficiently qualified to undertake a full review of primary health evidence, which, moreover, would not have been within the scope of this review. In reviewing and synthesising the evidence it should be noted that in the interests of time, in-text citations were not followed up and where citations to these remain only the citing references are included. The breadth of relevant evidence that the Scopus search provided meant that there was no scope to expand the search to other databases. However, Scopus provides access to a wide range of relevant journals and therefore this was not considered to hamper the findings significantly. The dependence on member countries and contacts to provide additional evidence clearly means that this review should not be considered to be comprehensive. However, as an expert-led, semi-systematic rapid evidence review the findings should provide a valuable contribution to inform the preparation of the EEA report.

Figure 1: Methodology flow chart



2 Policy context

2.1 Introduction to the standards under the Air Quality Directive and the thresholds under the END

In the EU, air and noise pollution are regulated separately. The Air Quality Directives (2004/107/EC and 2008/50/EC)[5] have set binding thresholds for concentrations of various air pollutants to be met by 2015 at the latest. Many EU Member States continue to exceed limit values (EEA, 2017) and some are currently subject to infraction proceedings relating for instance to the nitrogen dioxide (NO_2) and PM_{10} limit values. The Clean Air Policy Package[6] sets out a programme outlining measures to ensure that existing targets are met and setting out new air quality objectives for the period up to 2030, a revised National Emission Ceilings Directive (EU) 2016/2284[7], a new Medium Combustion Plants Directive (EU) 2015/21933[8] and a proposal to approve amended international rules on long-range transboundary air pollution (the Gothenburg Protocol) at EU level.

The Environmental Noise Directive (2002/49/EC)[9] aims to reduce the harmful effects of noise. It requires Member States to map noise levels from transport (road, rail and airports) and industry and to draw up action plans to address excessive noise pollution. The Directive does not set any limits or targets or prescribe specific measures to be taken, but leaves these decisions to the Member States. The European Commission together with the Member States are currently discussing Annex III related to the assessment methods for harmful effects and have updated and approved the revision of Annex II related to the assessment methods for the noise indicators throughout the Commission Directive (EU) 2015/996[10] of 19 May 2015 establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council.

2.2 Review of environmental policy

There is increasing evidence that indicates that people from lower socioeconomic backgrounds are more likely to suffer from exposure to noise and air pollution, which in turn creates health inequalities. Therefore, actions that address pollution should also consider the socioeconomic factors behind existing and potential differential health impacts. While the scientific evidence of the link between socioeconomic background, health inequality and noise and air pollution is growing (as the review of the literature in this report shows), few of the EU policies in place to address environmental stressors on health actually capture this issue. This section reviews the extent to which EU environmental policies have integrated social inequality factors to date. We consider both generic mentions of social inequality or SES and references to specific drivers of inequality as defined by the literature and used in existing indicators of SES (for example income, employment and working conditions, education levels, spatial segregation, access to health services, etc.) (Table 1).

For this report, through desk-based research, we identified 39 documents (

[5] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:152:0001:0044:en:PDF
[6] http://www.consilium.europa.eu/en/policies/clean-air/
[7] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.344.01.0001.01.ENG&toc=OJ:L:2016:344:TOC
[8] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32015L2193
[9] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0049
[10] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32015L0996

Appendix 2: List of documents analysed in the review of environmental policy (section 2.2)) with an environmental, and to a lesser extent, a health and spatial focus. We then conducted a qualitative content analysis to review the extent to which the key thematic legislation and the EU's over-arching environmental objectives (as laid out in the 7th Environmental Action programme (7EAP)) mention social inequality factors. Although an exhaustive review of all the many pieces of EU environmental legislation is beyond the scope of this report, we selected key strategies and directives falling within the scope of DG Environment and DG Climate Action. While we started by analysing the EU legislation on air pollution and noise, we then broadened the scope to include other topics, but still with particular attention to areas that have some relevance for these two thematic sectors (for example, green infrastructure or spatial planning). In addition, we included the objectives set out in the Declaration of the sixth Ministerial Conference on Environment and Health and its Annexes, the Urban Agenda for the EU, the Territorial Agenda 2020 and the Health Agenda 2020. This approach ensured that our sample was sufficiently representative of the wider EU environmental policy sector.

The evidence from the content analysis showed that, overall, the inclusion of socioeconomic factors within both over-arching environmental objectives and more sector-specific environmental directives is mixed. In particular, strategic and longer-term documents, albeit at different degrees, generally refer to societal challenges and link environmental protection to social inequality; by contrast, the consideration of socioeconomic factors within sector-specific directives is weaker. In this section, we will first discuss the results of the content analysis regarding the higher-level and longer-term documents, and then we will move on to discuss individual environmental directives or thematic strategies.

2.2.1 *Strategies, declarations and roadmaps*

At a global level, the Sustainable Development Goals (SDGs) set by the United Nations to replace the Millennium Development Goals (MDGs), aim at addressing a broad range of social, economic and development issues including, among others, fighting poverty, achieving good health and well-being for all, reduced inequalities, building sustainable cities and communities, as well as promoting climate action. The scale and breadth of the issues that the SDGs aspire to tackle highlight the linkages between socioeconomic factors and environmental protection. For example, fighting poverty (SDG 1) cannot be achieved without promoting well-being and health for all (SDG 3) and without reducing inequalities (SDG 10), including unequal access to health services. Moreover, climate action (SDG 13) is key to protecting more vulnerable people[11] from climate risks and, in return, sustainable city planning (SDG 11) is one of the driving factors for building resilient communities. Undercutting these issues, exposure to noise and air pollution exacerbates the risks to health particularly among poorer and more vulnerable populations, and this can constitute a further obstacle to inclusive and sustainable economic growth (SDG 8). It is clear that the linkages need to be addressed holistically, i.e. addressing environmental, social and economic concerns in an integrated way and in line with the principles of sustainable development.

The need to consider socioeconomic factors in conjunction with environmental protection is formalised in the EU's approach to pursuing the SDGs. In the European Commission's communication **"A Global Partnership for Poverty eradication and Sustainable Development after 2015"[12],** the integration of

[11] There is widespread consensus that the impacts of climate change will disproportionately affect poorer and more vulnerable populations (see, for example, Paavola 2017)
[12] This communication builds on two previous Communications "A decent life for all: ending poverty and giving the world a sustainable future" (2013) and "A decent life for all: from vision to collective action" (2014). The two communications were

the three dimensions of sustainable development in a balanced manner constitutes an overarching principle of the global partnership (p. 3). Following this communication, the 2015 Council Conclusion **"a New Global Partnership for Poverty Eradication and Sustainable Development after 2015"** also concurs and confirms that the challenges of poverty eradication and sustainable development are interlinked and need to be addressed as such in the post-2015 Agenda (p. 4).

Moreover, in 2016, the European Commission published the Communication **"Next Steps for a Sustainable European future. European Action for sustainability",** directly relates the EU's objective for a sustainable future to the UN's Sustainable Development Goals (SDGs) and states that 'Existing and new policies should take into account the three pillars of sustainable development, i.e. social, environmental and economic concerns' (p. 18). It also announced two work streams to integrate SDGs within European policy (p.3). The first work stream will have a strategic focus and will aim at integrating the SDGs in the Commission's priorities; the second one will look at implementing longer-term sustainability goals in sectoral policies. The extent to which SES and social inequality will feature in the two workstreams, or will be explicitly linked to exposure to pollution is still not clear at this stage.

At EU level, the linkages between exposure to noise and air pollution and SES constitute a major concern in the **Declaration of the Sixth Ministerial Conference of Environment and Health**, adopted in June 2017 by the Environment and Health Ministers of all member states in the European Region of the World Health Organization (WHO). In the document, the signatories note that pollution and environmental degradation disproportionately affect socially disadvantaged and vulnerable population groups (p. 2) and resolve to prevent premature deaths, diseases and inequalities related to environmental pollution and degradation (p.3). In the Annex accompanying the Declaration, Ministers commit to consider the social determinant of health, and to integrate environmental and social policies to reduce socioeconomic inequalities (p. 12). For example, actions should integrate health, environmental and equity targets into sectoral policies, like housing, transport, infrastructure strategies, land use, etc., to address different types of inequality (access to health services, access to green spaces, spatial segregation, etc.).

At EU level, from a health perspective, the interaction between health inequalities and social and environmental determinants is clear and it is prominent to defining the approach of the overall strategy. Indeed, the **Health 2020 strategy** includes the social and environmental dimensions among the determinants of health and health inequalities (p. 46) and, furthermore, it highlights that health inequalities can feed into further inequities in exposure to pollution and can 'amplify social disadvantage' (p. 47).

Socio-economic inequalities have increased in Europe since the mid-1970s[13], and intensified since the onset of the global financial crisis[14]. The **Treaty of Lisbon** calls on the EU to "*combat social exclusion and discrimination…. promote social justice and protection*" [15]. Recognising that these goals rest on the three pillars of economy, society and environment, the EU's social protection and cohesion policies call

followed, respectively, by two Council Conclusions on "An overarching post-2015 framework" (2013) and "A transformative post-2015 agenda" (2014).

[13] EU, 2010, Why socio-economic inequalities increase, EU, Luxembourg.

[14] OECD, 2017, Understanding the socio-economic divide in Europe, OECD, Paris France.

[15] Op cit. 1

for effective interaction between economic growth, job creation and the EU's Sustainable Development Strategy[16].

By contrast, despite the fact that all the documents with an environmental or spatial scope that we analysed build on the principle of sustainable development (which includes the three dimensions of social, economic and environmental sustainability), the social dimension and the link between socioeconomic and environmental factors are weaker. The **Europe 2020 strategy** for smart, sustainable and inclusive growth adopted back in 2010 sets ambitious poverty, climate change and resource efficiency targets, and recognises the need to design interventions to support groups at particular risk, such as one-parent families, elderly women, minorities, Roma, people with a disability and the homeless (p. 19). However, while the set of targets address poverty, climate change and resource efficiency, the interplay between these issues is overlooked. The **2011 Roadmap to a Resource Efficient Europe** refers to the need to integrate, at a macro-level, environmental, social and economic accounting systems in order to assess development and progress more comprehensively (p. 22), but, like the Europe 2020 strategy, it does not identify linkages between exposure to noise and air pollution and SES.

The **Energy Roadmap to 2050** (2011) highlighted the social dimension that EU policymakers have to consider along the path towards a new energy system, and that they should pay attention to the most vulnerable groups and design measures at national and local levels to avoid energy poverty. Although there is an increasing concern, from an air quality perspective, about the potential rising use of solid fuels as a response to energy poverty (Air Quality Expert Group, 2017), the Roadmap does not directly deal with this issue. Furthermore, the **2016 Urban Agenda for the EU**[17] considers urban poverty and air pollution as priority themes and urban regeneration, and it includes social, economic and environmental aspects' as cross-cutting issues (p. 7). The Urban Agenda for Europe acknowledges the structural dimensions of poverty in deprived urban neighbourhoods and calls for integrated approaches to urban regeneration, with a focus on air pollution and the social dimension of climate adaptation strategies[18]. However, as the thematic action plans were still being prepared at the time of writing, it was not possible to assess whether the Partnerships addressed these aspects in an integrated and holistic way.

Taking a closer look at the environmental sector, the **7th Environmental Action Programme (7EAP),** published in 2013, states the need to enhance the sustainability of the Union's cities (Art. 2(h)) and to make our societies more resilient (Annex, 1). Furthermore, a pillar of the 7EAP is the transition to an inclusive green economy, which includes, along with secure growth and development, the safeguard of human health and well-being, and the reduction of inequalities. In this regard, the document stresses that, in order to achieve an inclusive and green economy, the interplay between socioeconomic and environmental factors needs to be properly considered (Annex, 71). For example, with regards to air quality, the 7EAP highlights that policies need to focus particularly on areas where people who are *particularly sensitive or vulnerable groups of society*, are exposed to high levels of pollution (Annex, 45). Although the document does not define what sensitive or vulnerable groups of society are, given the explicit link made between socioeconomic factors and exposure, it is reasonable to assume the definition includes people from lower socioeconomic backgrounds. Moreover, the 7EAP also identifies the potential benefits that an increase in the ecological and climate resilience can bring in terms of

[16] European Commission (2005) Working together, working better: A new framework for the open coordination of social protection and inclusion policies in the European Union. Communication from the Commission COM (2005) 706 final, Brussels.
[17] For the purposes of this section, only the Pact of Amsterdam of the Urban Agenda for the EU was included in the analysis.
[18] EU, 2016, Urban agenda for the EU, Pact of Amsterdam, 30 May 2016, Amsterdam.

socioeconomic benefits, including for public health (Annex, 53). In the case of noise, in the 7EAP, the focus is on whole population exposure with the objective to "significantly decrease the noise pollution in the Union, moving closer to WHO recommended levels". The 7EAP also mentions that in order to achieve this objective, it is requested to "implement an updated Union noise policy aligned with the latest scientific knowledge, and measures to reduce noise at source, and including improvements in city design".

Specifically on the issue of air quality, the **2005 Thematic Strategy on Air Pollution** addresses the impact of air pollution on citizens' health and underlines that some groups are more vulnerable than others, but these are not defined based on socioeconomic factors. Furthermore, with regards to the EU strategy on Green Infrastructure (GI), the European Commission's Communication **"Green Infrastructure – Enhancing Europe's Natural Capital"** mentions place-based approaches to tackle the over-exploitation of natural resources, which is considered as a threat to territorial development (p. 3) and to the achievement of a smart, inclusive, and sustainable growth (the pillar of the Europe 2020 strategy). The Communication stresses that the implementation of GI can reduce social exclusion and isolation and benefit individuals and communities, including socio-economically (p. 3, 9). While the GI strategy recognises the positive effect that a better environment has on the quality of life of EU citizens, this is still not a reflection on the differential exposure to pollution due to SES.

Inclusive and sustainable growth heavily features in the **Territorial Agenda 2020** (published in 2011), which explicitly states that disparities in exposure to air pollution and noise (and the related health problems) in certain cases correlates with social inequality (p. 5). Furthermore, socioeconomic factors are also considered to be linked to territorial segregation – which, when translated into barriers to effective and sustainable transport connections, low accessibility to services, limited access to natural resources, ecological fragmentation and diminished social capital, demonstrates some of the factors linking exposure to pollution and health (p.8). By contrast, despite recognising that infrastructure is unequally developed across Europe (p. 4), the **2011 Roadmap to a Single European Transport Area** focused almost exclusively on the user or polluter pays principle, and does not mention social inequality and its effect on exposure to pollution. The 2011 Roadmap for moving to a competitive low carbon economy in 2050 mirrors a similar approach.

Finally, in relation to climate change, the **2013 EU Adaptation Strategy** stresses the need to give special attention to people and regions that are most exposed and already disadvantaged because of poor health, low income, inadequate housing and lack of mobility, thus explicitly linking low economic background to higher risks stemming from climate change. The ongoing evaluation of the EU Adaptation Strategy[19] provides an opportunity to explicitly integrate socio-economic dimensions more in climate change adaptation policies. Access to nature can reduce health inequalities[20] and there are opportunities to enhance green infrastructure within the EU's biodiversity strategy[21]. Green infrastructure delivers multiple benefits, including enhancing biodiversity, improving human health and well-being and supporting adaptation to climate change.

[19] European Commission, 2013, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'An EU Strategy on adaptation to climate change' (COM (2013) 216 final of 16 April 2013).
[20] ten Brink P., Mutafoglu K., Schweitzer J-P., Kettunen M., Twigger-Ross C., Baker J., Kuipers Y., Emonts M., Tyrväinen L., Hujala T., and Ojala A. (2016) The Health and Social Benefits of Nature and Biodiversity Protection. A report for the European Commission (ENV.B.3/ETU/2014/0039), Institute for European Environmental Policy, London/Brussels.
[21] European Commission, 2013, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Green Infrastructure (GI) — Enhancing Europe's Natural Capital, /* COM/2013/0249 final */

2.2.2 *Environmental Directives*

Environmental Directives and thematic strategies generally recognise that some groups can be particularly vulnerable to environmental impacts but, they often do not explicitly mention socioeconomic factors and the interplay between these and exposure to pollution. Reflecting the approach set out in the 2005 Thematic Strategy on Air Pollution, the Ambient Air Quality Directive (2008/50/EC) includes references to sensitive populations groups, including children. Moreover, it requires an evaluation of the estimated number of people exposed when developing an air quality management plan (Annex XV.A.2), but it does not indicate that Member States should consider socioeconomic factors when implementing the Directive, nor when developing air quality plans (Annex XV). The National Emission Ceilings Directive (2016/2284/EU) and the Medium Combustion Plants Directive (EU) 2015/21933 do not mention the condition of citizens from disadvantaged backgrounds and the consequences in terms of exposure or of regressive emission control policies. Similarly to the Ambient Air Quality Directive, the Environmental Noise Directive (2002/49/EC) also requires Member States to include in the action plans 'an evaluation of the estimated number of people exposed to noise, identification of problems and situations that need to be improved' (Annex V, 1). Moreover, it requires that 'if necessary, specific dose-effect relations could be presented for vulnerable groups of the population; different climates/different cultures (Annex III). Here, the Environmental Noise Directive mentions the need to consider specific circumstances, but this is not enough to conclude that it integrates consideration of SES specifically.

Broadening the scope to other topics, the consideration of SES and its interplay with exposure to pollution remains generic and not explicit. For example, the 2008 Marine Strategy Framework Directive (2008/56/EC) mentions that Member States should conduct an economic and social analysis "of their waters' use and of the cost of degradation of the maritime environment" (Whereas 24) and that they should give "due consideration of social and economic concerns in setting of targets" (Annex IV). The reference to social and economic concerns, however, appears to be too generic and not linked to inequality and differential exposure to pollution (or other environmental impacts) generated by maritime activities. Similarly, the 2011 Environmental Impact Assessment (EIA) Directive, includes in the definition of 'public concerned' [with regards public and private project] "public affected or likely to be affected by, or having an interest in, the environmental decision-making procedures". Again, while the literature suggests that people from low socio-economic background are indeed those "more likely to be affected", the Directive cannot be interpreted as specifically referring to SES or social inequality factors.

To conclude, the analysis suggests that while higher-level and longer-term documents within an environmental scope are likely to include references to socioeconomic factors, with some of them also looking at the interplay between social deprivation and exposure, the environmental directives do not integrate these aspects to date.

2.3 Table of definitions of socioeconomic status in the literature

Table 1 presents a review of different approaches to defining SES applied today, as well as a brief overview of how the SES of populations across Europe has evolved over the past 25 years. This review thereby helps to clarify some of the variability in defining the term in the literature that the SEP report identified.

Table 1: Review of approaches to defining socioeconomic status (SES)

Study	Brief description	Definition of SES
Adler et al (1994)	Study looking at the graded association of SES (at all levels) with health	SES is "a composite measure that typically incorporates economic status, measured by income; social status, measured by education; and work status, measured by occupation" (Dutton & Levine, 1989, p. 30)
Grundy and Holt (2001)	Study about how to measure SES and health inequalities	'The three most commonly employed indicators of SES in contemporary industrialised societies are income, education, and occupation. Choice of indicator may reflect preference for one theoretical pathway. If materialist explanations for health inequalities are preferred, then income would seem the most appropriate indicator. Behavioural influences might be hypothesised to relate more closely to education, while occupational characteristics or measures of relative deprivation, might be chosen by analysts wishing to investigate psychosocial links between SES and health. However, as all these indicators are interrelated and none of them capture in entirety domains identified as important in the theoretical literature, such an approach may be over simplistic'.
Duncan et al (2002)	Examination of the relationship between SES and mortality for a representative sample of individuals	'In general, indicators of SES are meant to provide information about an individual's access to social and economic resources. As such, they are markers of social relationships and command over resources and skills that vary over time. Among the most frequently used socioeconomic indicators are education and occupation. Economic indicators such as household income and wealth are used less frequently but are potentially as important as or more important than education and occupation.'
Tajik and Majdzadeh (2014)	Study looking at constructing a SES assessment to address health equality challenges	'SES is a combined indicator for social factors affecting health, which may include different factors including income, education, job, etc., and usually a combination of them is used for measuring effect of SES'
Hobza et al (2017)	Analysis of social inequalities in health	'SES is defined by employment, education and material wealth. People with a lower SES more commonly suffer from health problems such as heart disease, diabetes, hypertension, and overall mortality'
Institute for Research on Poverty (2016)	Study on the link between economic and social disadvantage and health	SES is determined by 'material living conditions as well as the factors that make healthy living conditions more or less likely (such as education, income, and being in a group experiencing discrimination)', which, in turn, 'are shaped by a wider set of forces, including most importantly economic, social and other public policies' (p. 3)
Urban Agenda for the EU 2016	New multilevel working method based on partnership to enhance	The Agenda stresses that SES is a combination of many and complex contributing factors. It

Study	Brief description	Definition of SES
	growth, liveability and innovation in EU cities and to tackle societal challenges	includes a Partnership aiming at reducing urban poverty. This Partnership will explore solutions that are both place-based solutions and people-based solutions.
European Commission (2016) The State of European Cities 2016	European Commission's report that analyses 'the performance of European cities with regards to the priority themes of the Urban Agenda for the EU (jobs and skills, poverty, climate change mitigation and adaptation, energy transition, air quality, mobility, etc.)' (p. 11).	The report considers people 'at risk of poverty or social exclusion (AROPE). The share of people at risk of poverty or social exclusion accounts for people who are in severe material deprivation (absolute poverty), relative poverty and/or live in a household where in the past twelve months the adults did not work or worked very little
European Commission, Directorate General for Regional Policy (2011) Cities of Tomorrow - Challenges, visions, ways forward (2011)	A European Commission's report that outlines the challenges that different European cities will face and set out a reflection on how to think about the future and achieve EU objectives, particularly in the implementation of the Europe 2020 strategy	The report's approach to SES considers poverty and social exclusion. Social Exclusion is linked to 'the distance to basic services such as education, health and social services, and the lack of satisfactory public transport to homes and work and education places
WHO. Health Impact Assessment (HIA) The determinants of health	Health Impact Assessment	Socioeconomic background is defined based on income and social status, other factors included that determine health outcomes have a social and economic component, such as education; employment and working conditions; social support networks; culture; access to health services. Determinants of health include also physical environment and person's individual characteristics and behaviours.
UK Government - Department for Communities and Local Government (2015) The English Index of Multiple Deprivation (IMD) 2015	Official measure of relative deprivation for small areas in England	This index SES based on 7 domains of deprivation: income; employment; education; health; crime; barriers to housing & services; living environment

This review of historical and current SES proxies has revealed similarities and discrepancies throughout their evolution. As the term suggests, its component parts are generally economic and social metrics, primarily income/poverty, employment and education. However, some sources also use social exclusion including access to services, discrimination and health. More recent examples have also introduced living environments as well, however care should be taken that metrics used as determinants of SES are not in fact effects of SES. Hence, proxies such as the English Index of Multiple Deprivation, which comprise different 'domains' can be useful for studies aiming to isolate specific determinants or to avoid autocorrelation of effect. It should be noted that SES proxies do not just vary temporally; studies undertaken in different countries will use different indices depending on available metrics

3 Update to the SEP report

Global/European trends

- In general, population exposure to noise pollution is decreasing;
- Exposure to air pollution has not decreased by as much, despite reducing emissions of most air pollutants. Largely due to:
    - continued exceedences of the AAQD limit values;
    - increased population size;
    - aging population; and
    - increased levels of air pollution in low-income and middle-income countries.

Spatial scales of impact

- Spatial scales of exposure to both air and noise pollution are complex;
- Spatial analysis of environmental inequality lacks a consistent, easily applicable, and empirically driven method of scale selection;
- Exposure relates primarily to urbanisation and direct proximity to source;
- Local variabilities are inherent;
- Differences in exposure over different spatial scales related to age and SES, contributing to environmental injustice through increased risk and vulnerabilities;
- Assessing spatial scales of exposure is further complicated by determination of personal exposures including residential, workplace/school and commuting.

Types of noise and air pollution

- Types of noise pollution have not changed since the SEP report and largely relate to source;
- Microplastics and unregulated chemical pollutants may be new types of air pollution.

Types of health impact

- Exposure to air and noise pollution may be associated with similar health impacts, e.g. cognitive performance, diabetes, hypertension, cardiovascular and cerebrovascular disease and mortality;
- Emerging evidence associates $PM_{2.5}$ and diabetes, decreased cognitive function, attention-deficit or hyperactivity disorder and autism in children, and dementia, in adults;
- Many of these are also associated with living in urban areas;
- Transportation noise was found to affect objectively measured sleep physiology and subjectively assessed sleep disturbance in adults. For the other outcome measures and noise sources examined the evidence was conflicting or only emerging;
- Relationships between air and noise pollution exposures (and other environmental exposures and health impacts) are likely to be more complex than additive.

Key sources of noise and air pollution

- Road traffic is the most significant source of both noise and air pollution in urban areas, where exposure is highest due to high population density;
- Agriculture is the main source of increasing ammonia (NH_3), itself an increasing source of secondary $PM_{2.5}$.

This section provides an update to the SEP report based on new sources and findings using longitudinal studies (where available). The update covers global/European trends, spatial scales of impact, types of noise and air pollution, types of health impact and key sources of noise and air pollution.

3.1 Global/European trends

Global and European trends for exposure to noise and air pollution are updated in the following sections. In general, population exposure to noise pollution is decreasing, whilst, despite reducing emissions of most air pollutants, exposure to air pollution has not decreased by as much. This is largely due to continued exceedences of the AAQD limit values, but also due to increased population size, aging population and increased levels of air pollution in low-income and middle-income countries.

3.1.1 *Noise*

In EU15 countries (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom), prevalence of complaints about noise from neighbours or from the street is higher among individuals living in relative poverty. This inequality is not apparent in NMS12 countries (Bulgaria, Czech Republic, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia) (WHO, 2012). In developing countries population exposed to environmental noise is expected to grow dramatically, coinciding with global urbanisation hotspots.

As highlighted in the update on the state of environmental noise in Europe (ETC/ACM, 2017) using the most recent noise exposure information from 2007 and 2012, more than 100 million people could actually be exposed to road traffic noise above 55 dB L_{den}, with more than 32 million people exposed to noise levels above 65 dB L_{den}. These numbers are based on estimations based on calculated figures complementing current data reported on noise exposure by EEA member countries.
One in eight persons living in cities with more than 100,000 inhabitants is exposed to night noise levels higher than 55 dB L_{night} (ETC/ACM, 2017), the current interim target established by WHO in view of decreasing the noise levels into 40 dB L_{night}. New guidelines on exposure response curves are currently being prepared by WHO, which will potentially modify those thresholds based on new scientific evidence.

As observed during the period 2007-2012, the balance between the number of people exposed to the different noise sources is a net decrease of the total population exposed, although the completeness of both data sets influence the trends observed and listed below and should be revisited once the noise exposure datasets are complete:

- Decrease of the number of people exposed to road traffic noise above 55 dB L_{den} of 20 million people (calculations done with 2007 exposure data as basis);
- Decrease of the number of people exposed to rail noise of about 1.4 million people; to aircraft noise of 400,000 people and to industrial noise of 300,000 people, also considering L_{den} indicator above 55 dB;
- In cities, all possible patterns and trends in relation to changes in people exposed to different noise sources have been encountered: decrease and increase by different degrees and also no change. In general, agglomerations above 750,000 inhabitants are those with higher relative decrease of population exposed.

At the end of 2017, noise exposure data corresponding to the new reporting cycle have been delivered by member countries. This information is currently being quality checked and analysed, and will be checked if the trends observed between the period 2007 – 2012 are the same ones that could be analysed considering 2012 – 2017.

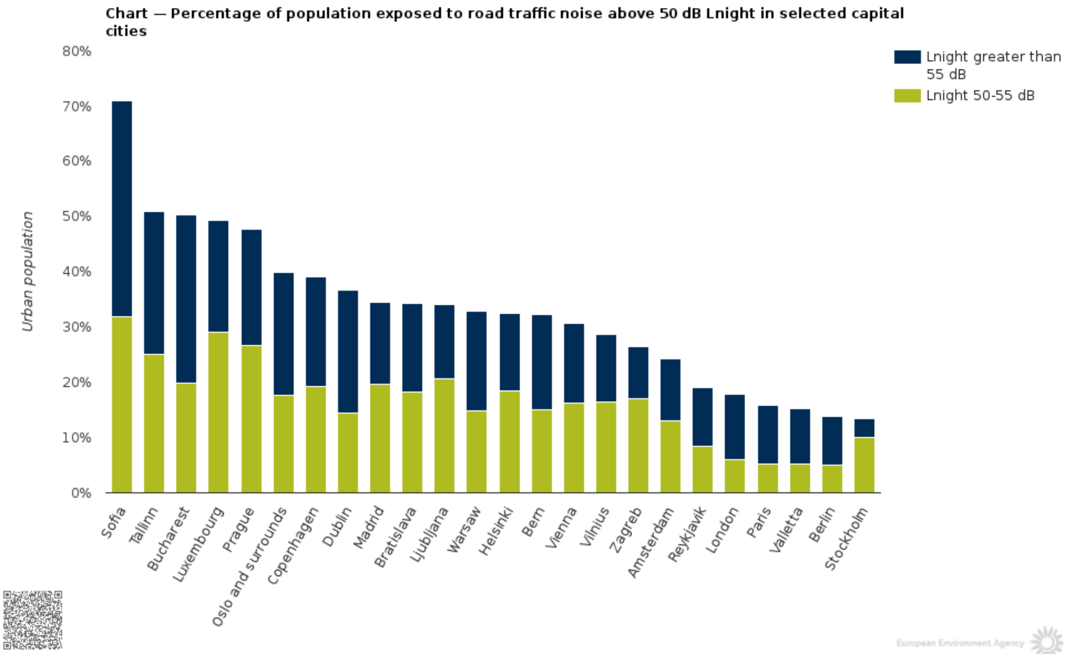
In ETC/ACM (2017), the health impact of environmental noise as a result of these exposures in all END assessment areas provided the following figures:

- 14.7 million adults are severely annoyed by noise,
- 6.1 million adults are highly sleep disturbed by noise,
- 72,000 hospital admissions per year
- and 16,600 cases per year of premature mortality, are the most accurate

The contribution of road traffic noise to the health impact of all noise sources in the END assessment areas has been estimated as 80-85%, of which about 70% occurs in the agglomerations. Indicative results suggest that health impact of road traffic noise in the END assessment areas reflects 25-45% of the total burden due to road traffic noise in Europe, depending on the health effect considered.

Figure 2 shows the percentage of inhabitants exposed to road traffic noise levels greater than 55 dB L_{night} and between 50 and 55 dB L_{night}. The END requests exposure data to be collected above 50 dB L_{night} while WHO considered 40 dB L_{night} as a health-based limit value of the night noise guidelines necessary to protect the public, including most of the vulnerable groups such as children, the chronically ill and the elderly, from the adverse health effects of night noise. An interim target of 55 dB L_{night} is recommended in situations where the achievement of 40 dB L_{night} is not feasible, although this limit is not a health-based limit value by itself and vulnerable groups cannot be protected at this level, so it should be considered as a feasibility-based intermediate target which can be temporarily considered by policy-makers for exceptional local situations (WHO, 2009).

Figure 2: Percentage of population exposed to road traffic noise above 50 dB L_{night} in selected capital cities (Source EEA, 2017[22]. Last modified 18 Aug 2017)



[22] https://www.eea.europa.eu/data-and-maps/daviz/percentage-of-population-exposed-to-3#tab-chart_1

3.1.2 *Air*

The following section provides evidence of global and European trends relating to air pollution concentrations and emissions. As evidenced in this section, concentrations of key pollutants (PM, O_3) continue to increase globally, and across Europe many countries continue to exceed EU standards of direct impact to human health (PM, O_3, NO_2, BaP).

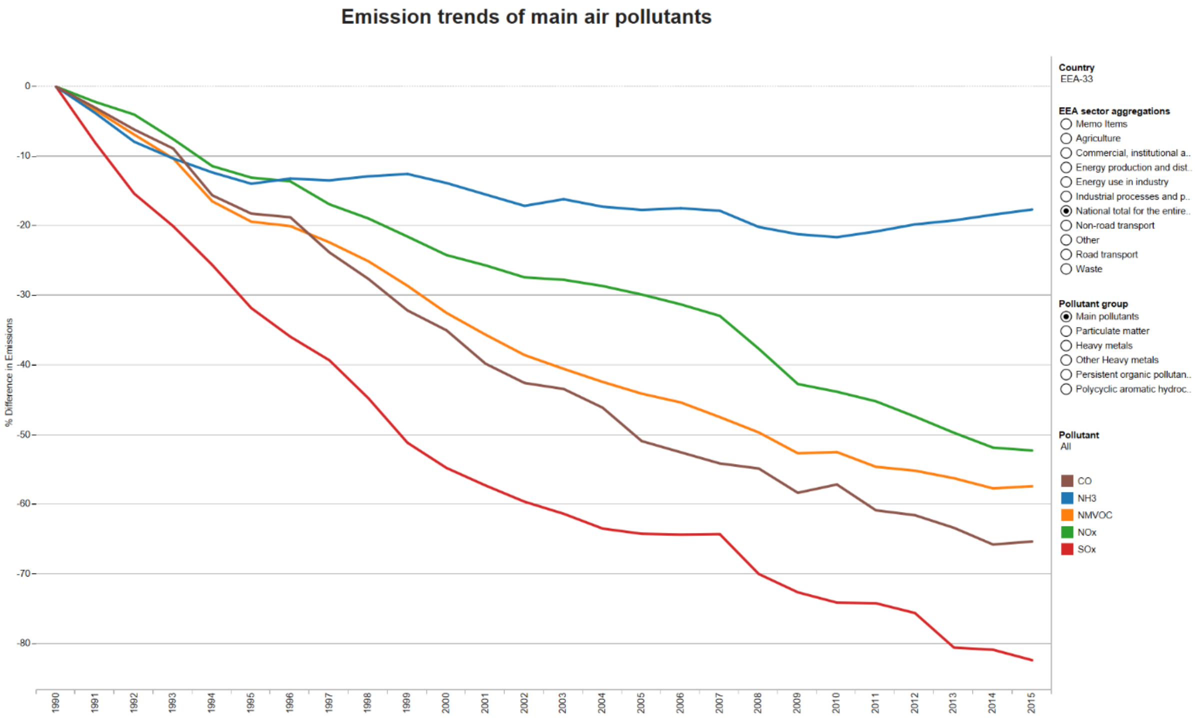
Global population-weighted $PM_{2.5}$ increased by 11.2% from 1990 (39.7 µg/m^3) to 2015 (44.2 µg/m^3), increasing most rapidly from 2010 to 2015. Among the world's ten most populous countries, exposures since 2010 increased in Bangladesh and India and were stable but remained high in Pakistan and China. Population-weighted ozone levels increased by 7.2% globally from 1990 (56.8 parts per billion [ppb]) to 2015 (60.9 ppb). Within the world's ten most populous countries, increases of 14–25% were noted in China, India, Pakistan, Bangladesh, and Brazil, with smaller increases in Japan and negligible changes in Russia and Nigeria (Cohen et al., 2017).

Concentrations of PM continued to exceed the EU limit values in large parts of Europe in 2015, especially for PM_{10}. In 2015, 18 of the EU-28 and four other European countries registered concentrations above the EU O_3 target value for the protection of human health. The annual limit value for nitrogen dioxide (NO_2) continues to be widely exceeded across Europe, with around 10% of all the reporting stations recording concentrations above that standard in 2015 in a total of 22 of the EU-28 and three other reporting countries. 89% of all concentrations above this limit value were observed at traffic stations. Concentrations of benzo[a]pyrene (BaP) exceeded the EU target value in 14 Member States, in particular in central and eastern Europe (out of 22 Member States and two other countries reporting measurements of BaP with enough valid data in 2015). Only six European stations reported sulphur dioxide (SO_2) concentrations above the EU daily limit value in 2015. However, 30% of all the stations measured SO_2 levels exceeding the WHO AQG in 2015 (EEA, 2017).

In many EU countries air quality has improved in recent years, but exceedences of the AAQD limit values are still widespread 8 or 13 years after the dates to be achieved. The European Commission is currently taking legal action for non-compliance with limit values (for NO_2) against 13 Member States, with ongoing infringement cases against Austria, Belgium, the Czech Republic, Denmark, France, Germany, Hungary, Italy, Poland, Portugal, Spain and the United Kingdom, and Luxembourg. Nine of these Member States (including Romania and Slovakia) have already received a Reasoned Opinion and for which the next stage in the infringement procedure would be a referral to the Court of Justice. For PM_{10}, there are currently cases against 16 Member States (Belgium, Bulgaria, the Czech Republic, Germany, Greece, Spain, France, Hungary, Italy, Latvia, Portugal, Poland, Romania, Sweden, Slovakia, and Slovenia), and two of these cases (against Bulgaria and Poland) have been brought before the Court of Justice of the EU with the European Court of Justice having passed a ruling as regards PM_{10} exceedances in Bulgaria in April 2017 (European Commission, 2018).

Contrary to continued exceedences of the EU limit values, total emissions of most pollutants are decreasing across the EU, although the pattern is heterogeneous between countries. Total EEA emissions of sulphur dioxide, nitrogen dioxide, ammonia and ‘other compounds’ reduced between 2000 and 2009 by 48%, 25.77%, 10.2% and 29.65% respectively (Figure 3). Most countries have reduced emissions, but in a few cases emissions have increased. In some countries (e.g. Malta, Bulgaria, Greece, the Netherlands, Belgium) emissions remain relatively high, in some cases despite already achieving heavy reductions of emissions (Huete-Morales et al., 2017).

Figure 3: Trends in total emissions (main pollutants) for EEA countries 1990-2015 (Source: EEA, 2017[23])



Europe's most serious pollutants in terms of harm to human health are PM, NO_2 and ground-level O_3. All primary and precursor emissions contributing to ambient air concentrations of PM, O_3 and NO_2 decreased between the years 2000 and 2015 in the EU-28 and the EEA-33. The smallest reduction was for NH_3 (8% reduction in the EU-28 and 4% reduction in the EEA-33) and the largest was for SOx (72% reduction in the EU-28 and 61% reduction in the EEA-33) (EEA, 2017).

Huete-Morales et al. (2017) found that emissions of sulphur oxide varied widely among the EU countries surveyed. The lowest values recorded in 2009 corresponded to Latvia (0.063 thousand tons per km^2) and Sweden (0.073), while the highest were found in Malta (24.817), followed at a considerable distance by Bulgaria (5.927) and Greece (3.237). The mean overall of emission level of sulphur oxide was 2.196 (1.326 excluding Malta). The evolution of these emissions over time is, nevertheless, very encouraging, since almost all countries have reduced their emissions since 2000, with an average reduction for the EU as a whole (excluding Luxembourg) of approximately 48%. Nitrogen oxide emissions in 2009 also varied widely. The lowest values were recorded in Sweden (0.364 thousand tonnes per km^2), Latvia (0.440), and Finland (0.501), and the highest in Malta (27.083), the Netherlands (8.118), and Belgium and Luxembourg (above 6 in each case). The average level in the EU was 3.534 (2.629 excluding the anomalously high value of Malta). Compared to 2000, overall EU emissions fell by 25.77%, although results were very heterogeneous. The average level of ammonia emissions in the EU in 2009 was 1.137 tons per km^2 – a reduction of 10.2% with respect to 2000. Again, Malta recorded the highest value (5.120), followed by the Netherlands (3.691) and Belgium (2.153). Sweden (0.117), Finland (0.120), and Estonia (0.229) reported the lowest rates. Most countries reduced their emissions compared to 2000 – especially in Bulgaria (52.98%) and the Netherlands (22.89%) – and emissions increased in only four countries, with the highest increase being recorded in Latvia (26.34%). The mean level of emissions of

[23] https://www.eea.europa.eu/data-and-maps/dashboards/air-pollutant-emissions-data-viewer

'Other compounds' in 2009 was 2.034 tons per km^2, which represents a decrease of 29.65% compared to 2000 (Huete-Morales et al., 2017).

Reduction in European PM emissions are, largely due to the implementation of EU legislation, mainly focused on road transport and large point sources, however, emissions released by residential solid fuel appliances have been increasing due to a lack of regulations, a tendency that is expected to change with the Ecodesign Directive[24]. The decrease of traffic PM exhaust emissions has also increased the importance of traffic non-exhaust emissions, a major source of metals in urban areas (Guevara, 2016).

3.2 Spatial scales of impact

Spatial scales of exposure to both air and noise pollution are complex and relate primarily to urbanisation and direct proximity to source, although local variabilities are inherent. Differences in exposure over different spatial scales is furthermore related to age and SES (e.g. Padilla et al., 2016a), contributing to environmental injustice through increased risk and vulnerabilities. Assessing spatial scales of exposure is further complicated by determination of personal exposures including residential, workplace/school and commuting.

3.2.1 *Noise*

At present, spatial analysis of environmental inequality lacks a consistent, easily applicable, and empirically driven method of scale selection (Kedron, 2016). Reported outcomes from studies dedicated to empirically demonstrate a direct relationship between SES and exposure to environmental noise presented a heterogeneity of findings partly explained by its dependency on the spatial scale and population assignment strategies (Most et al., 2004). Dependency on scale is even more evident in studies to assess cause-effect relationship between SES population exposed to noise and health implications.

Scale is also relevant to evaluate whether actions taken to improve noise quality have resulted in reduced health effects. Spatial scales of intervention and effects will vary from highly local (e.g. noise barrier on a particular roadway) to regional, national (emission limits for motor vehicles), or international (e.g. emission limits for aircraft) (Brown and van Kamp, 2017).

3.2.2 *Air*

Urbanisation and urban density relations with exposure to air pollution are demonstrated in the following studies. In a socio-spatial distribution study of ambient air exposure in Berlin, planning areas (PLAs) with a high/very high development index (DI) are only exposed to low or medium levels of air pollution. In more than half of the PLAs with a medium DI, medium pollution levels occur, about a third of these PLAs exhibit very high and high pollution levels. PLAs with a low and very low DI predominantly exhibit medium levels of $PM_{2.5}$ and NO_2 air pollution, but some high-level and very high-level pollution also occurs (UMID, 2011). Urban density has a negative influence on road transport energy use and the impacts of urbanization depend on the level of urban density (Liu et al., 2017). In Polish cities >100,000 citizens (Krakow, Warsaw) the average CO concentration in atmospheric air was 2–4 times higher than in Kozienice (<100,000 citizens) (Maga et al., 2017).

[24] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0125

Padilla et al. (2016a) identified city-specific patterns of spatial inequalities in infant and neonatal mortality over time. The influence of deprivation index and NO_2 exposure in the geographic variation of these outcomes differs depending on the area and time period. Whereas SES explains a large part of the spatiotemporal variability of infant mortality, NO_2 concentrations only appear to explain some of the spatial variability of neonatal mortality in the study area of Lille. The role of environmental exposures should be interpreted cautiously, since NO_2 alone was considered, nevertheless, the data suggest that environmental exposures may influence observed socioeconomic inequalities.

In the RESPOZE study the magnitude of personal ozone concentrations was inversely associated with population density among residential areas in two Greek cities. Apart from the connection with primary NO emissions, population density is considered to have a diminishing effect on ozone through its depletion on building surfaces. Positive associations between personal ozone exposure and altitude were recorded, primarily resonating the spatial variability of ambient levels, with higher concentrations typically recorded in suburbs with higher terrain elevation in both cities (N-NE sector in Athens, Panorama in Thessaloniki) (Grivas et al. 2017).

Urban/rural distinctions have also been observed in the literature. Annual mean concentrations of air pollution (simulated for 2010) were assigned to the 1.2 million residential postcodes in England, of which a quarter were classified as rural. Generally, concentrations of total $PM_{2.5}$ and PM_{10}, sulphate and primary $PM_{2.5}$ were higher in urban than in rural areas based on both simple arithmetic mean and population-weighted mean pollution levels; the reverse was true for O_3, nitrate $PM_{2.5}$ and, for more deprived areas, $PM_{2.5}$–PM_{10} (Milojevic et al., 2017). However, in a questionnaire survey of 454 Danish residents, perceived air pollution (odour, smoke, and dust) in the Danish countryside appears to be comparable to that in urban areas (mainly due to odour exposures from agriculture) (Blanes-Vidal, 2017).

Local variations in exposure to industrial emissions can depend on specific source. Gianicolo, Mangia and Cervino (2016) found two exposure patterns characterised by high mortality levels: a proximal one characterised by exposure to PM_{10} and a distal one characterised by exposure to SO_2. The former affects residents close to the industrial site and is largely associated with the extensive diffuse and fugitive emissions derived from the industrial site; the latter impacts residents at a distance downwind from the industrial site, and is likely associated with emission of pollutants from taller stacks (Gianicolo, Mangia and Cervino, 2016).

Exposure to road traffic emissions are also related to proximity to source. Exposure to CO, NOx, and ultrafine particles (UFP) is high on-road, and also within the first 150 m of a major way. Thus, pedestrians, cyclists and drivers are directly exposed to the sources (Pasquier and André, 2017). Spatially speaking, cyclists riding for recreation and other purposes are more likely to be exposed to relatively low levels of air pollution than cyclists riding for commuting (Sun and Mobasheri, 2017).

3.3 Types of noise and air pollution

3.3.1 *Noise*

Types of noise pollution have not changed since the SEP report[25] and largely relate to source (Table 2).

Table 2: Types of noise and air pollution from the original SEP report

Sources categories	Key noise emitters	Key air emissions
Transport	• Aircraft • Road traffic • Rail • Ports, docks and shipping	• Particulate matter (PM), especially from road transport • Volatile organic compounds (VOCs) • Carbon monoxide (CO) • Nitrogen oxides (NOx), especially from diesel cars • Sulphur oxides (SOx), especially from shipping • Greenhouse gases (GHGs) from all sources (74% of CO2 from road sources, 12% from aviation)
Industry (non-farming)	• Heavy machinery • Construction • Energy generation including from wind turbines	• SOx from burning of fossil fuels and industrial processes • PM from commercial/institutional fuel burning • GHGs from burning of fossil fuels
Agriculture	• Heavy machinery • Livestock	• Methane from livestock and manure • Nitrous oxide (N2O) from soil management practices
Household and neighbourhood (minimal contribution)	• Music and TV • People — at home, school and workplace • Pets • Garden equipment • Church bells • Entertainment venues	• PM from household fuel-burning • GHGs from home and community energy use

3.3.2 *Air*

Outside of the legislated air pollutants covered by the Ambient Air Quality Directive (2008/50/EC) and National Emissions Ceiling Directive (2016/2284/EU), new and potentially problematic pollutants are coming to the fore, including microplastics and unregulated chemical pollutants (Prata, 2018; Landrigan et al., 2017). We have heard a lot about the presence of plastics in our oceans and the bioaccumulation risks to animal and human health. However, microplastics have also been detected in atmospheric fallout and synthetic fibres have already been detected in human lung biopsies. According to Prata (2018) low toxicity particles such as microplastics may cause disease by dust overload, oxidative stress and translocation in susceptible individuals. Furthermore, injury or death may occur as a result of chronic exposure to airborne microplastics (Prata, 2018).

[25] http://ec.europa.eu/environment/integration/research/newsalert/pdf/air_noise_pollution_socioeconomic_status_links_IR13_en.pdf (see section 1.3)

In addition to Table 2, although not a new pollutant, emissions of ammonia (NH_3) are showing a steady increase across Europe, contributing to secondary PM (see section 3.5.2).

3.4 Types of health impact

Studies presented here highlight that exposure to air and noise pollution may be associated with similar health impacts, e.g. cognitive performance, hypertension and cardiovascular and cerebrovascular disease and mortality, many of which are also associated with living in urban areas. Relationships between the respective exposures are likely to be more complex than additive.

3.4.1 *Noise*

The WHO regional office for Europe (WHO/Europe) is currently developing the WHO Environmental Noise Guidelines for the European Region. It is expected that the new guidelines will be published in the course of 2018.

In the framework of the update of the WHO community guidelines seven papers were published in a special issue of the IJERPH (Lercher, de Kluizenaar and Aasvang, 2017). These pertained to cardiovascular effects, cognitive effects, annoyance, interventions, low birthweight, hearing problems, sleep disturbance and cognitive effects.

Since the results of WHO/Europe were not available when this report is being prepared, the health impact assessment was carried out with the same methods (exposure-response relations) as applied in the Noise in Europe 2014 report (EEA, 2014) (More detail about the methods applied can be found in Houthuijs et al. (2014)), and a summary of the new evidence is indicated per health outcome at the end of each specific subsection.

The health impact assessment was carried out for 32 countries (EU28, Iceland, Liechtenstein, Norway and Switzerland). The results presented are aggregates of the results for these countries.

Annoyance and sleep disturbance

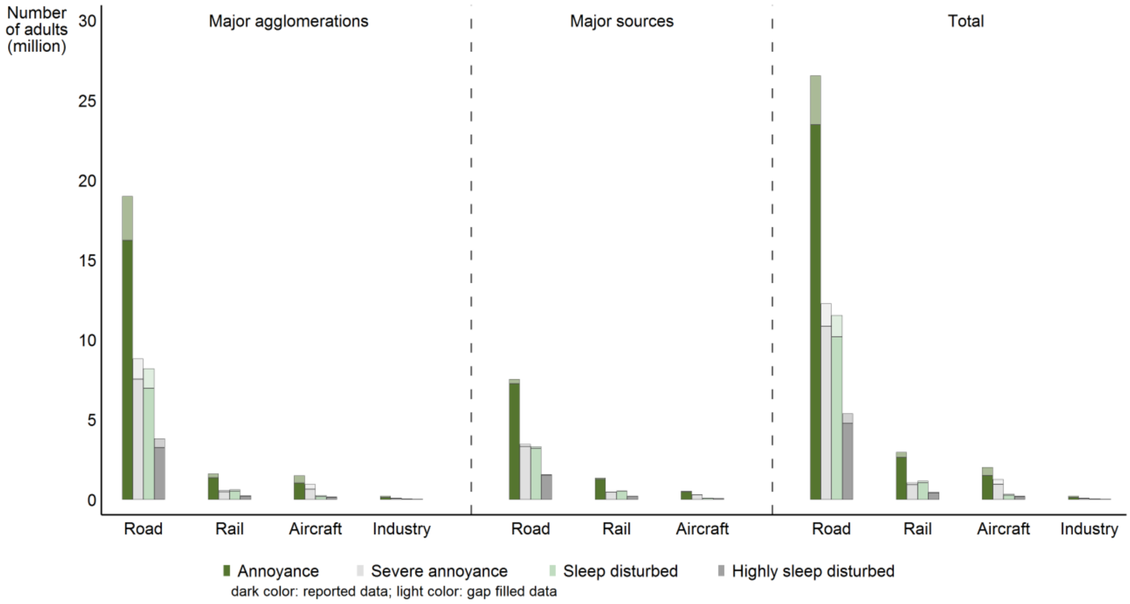
Based on the noise data reported by countries for 2012, around 27.6 million adults living in agglomerations or near major sources with noise levels equal to or above 55 dB L_{den} may be considered as being ‘annoyed’ by noise from road traffic, railways, aircrafts or industry; 12.8 million of them are ‘severely’ annoyed. Adding the gap filled noise exposure data (methodology that can be found in: https://forum.eionet.europa.eu/etc-acm-consortium/library/subvention-2017/task-deliveries-ap2017/task-1119-noise-data-operational-compilation-and-management/b.-final-drafts-approval-eea/subtask-6.-end-gap-filling/etc_acm_wp_gapfilling_171109), the results show an increase of the total number of adults being annoyed by noise to around 31.7 million and 14.7 million of them are ‘severely’ annoyed (ETC/ACM, 2017).

The distinction between ‘annoyed’ and ‘severely annoyed’ was already established by Mediema and Vos in 1998, deriving exposure-response relationships for transportation noise and confirmed in the latest WHO reviews: Guski et al (2017) in the case of annoyance and Basner and Mcguire (2018) in the case of sleep disturbance.

Similarly, it was assessed that 11.5 million adults have sleep disturbance due to night time noise levels equal to or above 50 dB L_{night} from road traffic, railways, aircraft or industry. About 5.3 million of them are highly sleep disturbed. Supplementing the reported END data with gap-filled data, the impact is enlarged to 13.1 million adults with sleep disturbance. 6.1 million of them are highly sleep disturbed (ETC/ACM, 2017).

In Figure 4, the results for annoyance and sleep disturbance based on the reported and gap filled END data are presented according to the noise source and the location of the assessment. As shown in the figure based on the reported and gap filled END data, about 85% of the burden of annoyance and sleep disturbance is related to road traffic noise, of which about 70% occurs in the agglomerations.

Figure 4: Estimated number of adults with (severe) annoyance and estimated number of adults that are (highly) sleep disturbed according to the noise source and location of the assessment, based on the reported and gap filled END data (ETC/ACM, 2017)



The systematic review and meta-analyses on effects of environmental noise on annoyance were performed by Guski et al (2017). The noise sources include aircraft, road, and rail transportation noise as well as wind turbines and noise source combinations. Again, the time frame between 2000 and 2014 and selected papers included those providing comparable acoustical and social survey data including exposure-response functions between noise exposure and annoyance. The search resulted in 62 studies, of which 57 were selected for quantitative meta-analyses. For the meta-analysis additional data were obtained where needed. Risk of bias was assessed by means of study characteristics for individual studies and by funnel plots to assess the risk of publication bias. Tentative exposure-response relations for the percentage of highly annoyed residents (%HA) in relation to noise levels for aircraft, road, rail, wind turbine and noise source combinations were derived. Using the grading system, the evidence of exposure-response relations between noise levels and %HA was evaluated as moderate for aircraft and railway and low for road traffic and wind turbines. The strength of the evidence is also dependent on the pooled sample sizes. Main limitations are due to the variance in the definition of noise levels and %HA. The increase of %HA in newer studies of aircraft, road and railway noise at comparable L_{den} levels of earlier studies point to the necessity of adjusting noise limit recommendations.

The systematic review by Basner and Mcguire (2018) evaluated the strength of the available evidence on the effects of environmental noise exposure on sleep. 74 studies predominately conducted between 2000 and 2015 were included in the review. A meta-analysis of surveys linking road, rail, and aircraft noise exposure to self-reports of difficulty falling asleep, awakening during the night, and sleep disturbance was conducted. Pooled analysis of polysomnographic studies on the acute effects of transportation noise on sleep was also performed. Due to a limited number of studies and the use of different outcome measures, a narrative review only was conducted on the effect of transportation noise on motility, cardiac and blood pressure outcomes, and on children's sleep. The effect of wind turbine and hospital noise on sleep was also assessed. Results showed a significant association between a 10 dB increase in the average night time noise level and self-reported sleep disturbance for aircraft (1.936; 95% CI 1.608–2.332), road (2.126; 95% CI 1.820–2.483), and rail (3.058; 95% CI 2.378–3.933) noise. For polysomnographically measured sleep, the unadjusted odds ratio for the probability of awakening for a 10 dB increase in the indoor maximum noise level was also significant for aircraft (1.351; 95% CI 1.218–1.499), road (1.360; 95% CI 1.192–1.550), and rail (1.354; 95% CI 1.209–1.515) noise.

Transportation noise was found to affect objectively measured sleep physiology and subjectively assessed sleep disturbance in adults. For the other outcome measures and noise sources examined the evidence was conflicting or only emerging (Basner and McGuire, 2018).

Reading impairment, hypertension, and cardiovascular disease and premature mortality

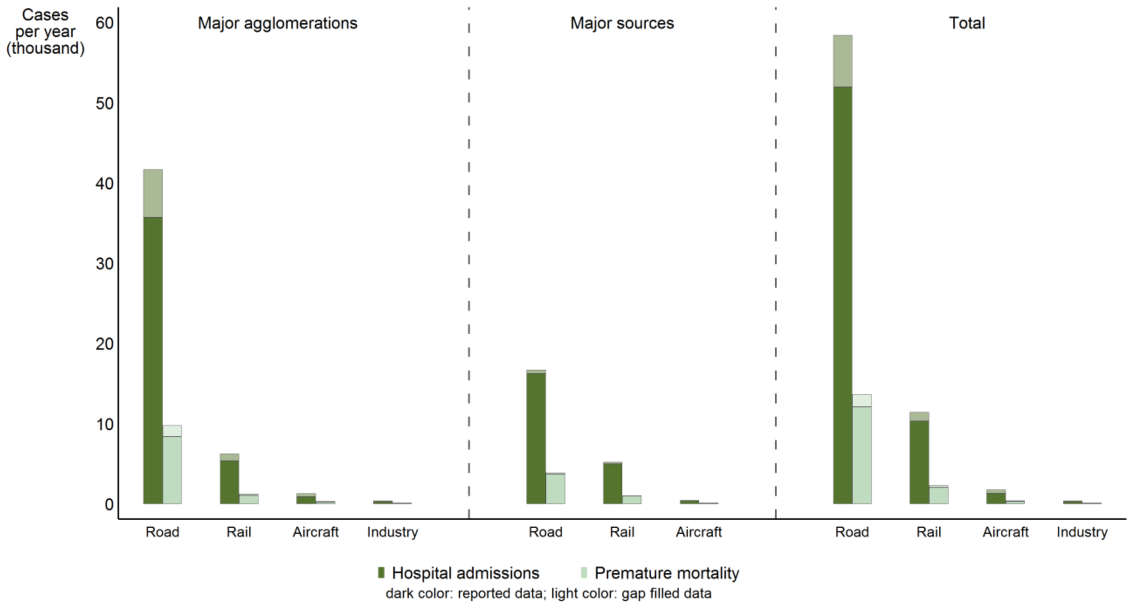
It is estimated that almost 13,000 children aged of 7 to 17 year old have a reading impairment attributed to exposure to noise from aircrafts. Three quarters of them are children in agglomerations (ETC/ACM, 2017).

Based on the reported END data, the exposure to environmental noise contributes to 1.3 million prevalent cases of hypertension among adults. This number increases to 1.5 million prevalent cases when the missing END data is gap filled (ETC/ACM, 2017).
Hypertension increases the risk for coronary heart and cerebrovascular diseases, and also increases the risk for premature mortality due to coronary heart and cerebrovascular disease. The total number of hospital admissions for these diseases related to noise exposure is estimated to be almost 63,000 cases per year, based on the reported data and 72,000 cases per year, based on reported and gap filled END data (ETC/ACM, 2017).

For premature mortality, it is estimated that noise could contribute to 14,500 premature deaths per year, based on the reported data; and 16,600 deaths per year based on reported and gap filled data. About two thirds of the burden of disease is related to coronary heart disease and one third to cerebrovascular disease (ETC/ACM, 2017).

In Figure 5, the results for hospital admissions and premature mortality based on the reported and gap filled END data are presented according to the noise source and the location of the assessment.

Figure 5: Estimated cases per year of hospital admissions and premature mortality due to coronary heart and cerebrovascular diseases, according to the noise source and location of the assessment based on the reported and gap filled END data (ETC/ACM, 2017)



To update the current state of evidence and assess its quality, a systematic review on the effects of environmental noise exposure on the cardio-metabolic systems was undertaken (van Kempen et al, 2017). Effects of noise from road, rail and air traffic, and wind turbines on the cardio-metabolic system, published between 2000 and 2015 were included in the review. 61 studies allowed for the estimation of exposure response relationships. These studies were used for meta-analyses, and assessments of the quality of evidence using the Grading of Recommendations Assessment, Development and Evaluation (GRADE). Many studies concerned traffic noise and hypertension, but these were in most cases cross-sectional and suffering from a high risk of bias. The most comprehensive evidence was found for road traffic noise and Ischemic Heart Diseases (IHD). The evidence was rated as high. Pooled analysis revealed a Relative Risk (RR) of 1.08 (95% CI: 1.01–1.15) per 10 dB (L_{den}) for the association between road traffic noise and the incidence of IHD. Only a few studies reported on the association between transportation noise and stroke, diabetes, and/or obesity, with a moderate to low level of evidence.

The systematic review on cognitive effects (Clark and Paunovic, 2018) assesses the quality of the evidence across individual studies on the effect of environmental noise (road traffic, aircraft, and train and railway noise) on cognition. Quantitative non-experimental studies of the association between environmental noise exposure on child and adult cognitive performance published up to mid-2015 were reviewed: no limit was placed on the start date for the search. A total of 34 papers were identified, all of which were of child populations. A range of cognitive outcomes was examined. The quality of the studies was graded as moderate quality for an effect for some outcomes and sources. The evidence was strongest for the association between aircraft noise effects on reading comprehension and long-term memory. For other cognitive outcomes and sources the evidence is weak, not because there are no effects but because more studies of high quality design are needed.

The objective of the review hearing outcomes (Sliwinska-Kowalska and Kamil Zaborowski, 2017) was to assess whether an exposure-response relationship can be established between exposures to non-occupational noise and permanent hearing outcomes such as permanent hearing loss and tinnitus. In contrast to some of the other reviews no time frame was defined for the literature search except for personal listening devices (PLDs) using a time period between 2008 and 2015. Studies were included which measured noise in sound pressure levels (SPLs) and expressed in individual equivalent decibel values (LEX,8h), included both an exposed and reference groups, and defining the outcome in terms of a permanent health effect (hearing loss, tinnitus, etc.). Meta-analysis was not possible due to methodological heterogeneity of included studies and the inadequacy of data. Only five studies fulfilled the inclusion criteria, all related to PLDs and addressing hearing loss as the outcome or tinnitus. Results showed an association between noise level and hearing loss in all three of the studies on hearing loss. One study showed an association between the duration of PLD use and hearing loss. No association was confirmed between prolonged listening to loud music through PLDs and tinnitus. The evidence was graded as low quality and it is recommended to perform more studies.

The review on adverse birth outcomes in relation to environmental noise exposure (Nieuwenhuijsen, Ristovska and Dadvand, 2017) was aimed at reviewing the evidence for the World Health Organization (WHO) noise guidelines and conduct an updated systematic review of environmental noise, specifically aircraft and road traffic noise and birth outcomes, such as preterm birth, low birth weight, being small for gestational age and congenital malformations. All the papers on environmental noise and birth outcomes in previous systematic reviews were included and updated (timeframe 2014-2016). Further inclusion and exclusion criteria for the studies provided by the WHO expert group were applied. In total, 14 studies are included in this review, six studies on aircraft noise and birth outcomes, five studies on road traffic noise and birth outcomes and three related studies on total ambient noise (in most cases traffic noise). The number of studies on environmental noise and birth outcomes is small and the quality of evidence generally ranges from very low to low, particularly in case of the older studies. The limited number of studies did not allow for meta-analyses. Very low quality evidence was found for associations between aircraft noise and preterm birth, low birth weight and congenital anomalies, and low quality evidence for an association between road traffic noise and low birth weight, preterm birth and small for gestational age.

It is of note also that people who submit noise complaints to the competent authorities generally come from a fairly high socio-cultural background. They are not necessarily more annoyed than others, but simply know their rights better and expect to be listened to (Inpes, 2007). Moreover, it should be taken into consideration the cognitive distortions that we may face, such as agreeing with statements like “the effects of noise are overestimated”, usually more commonly stated among lower educated participants in an Austrian study (Lercher et al., 2005), for example.

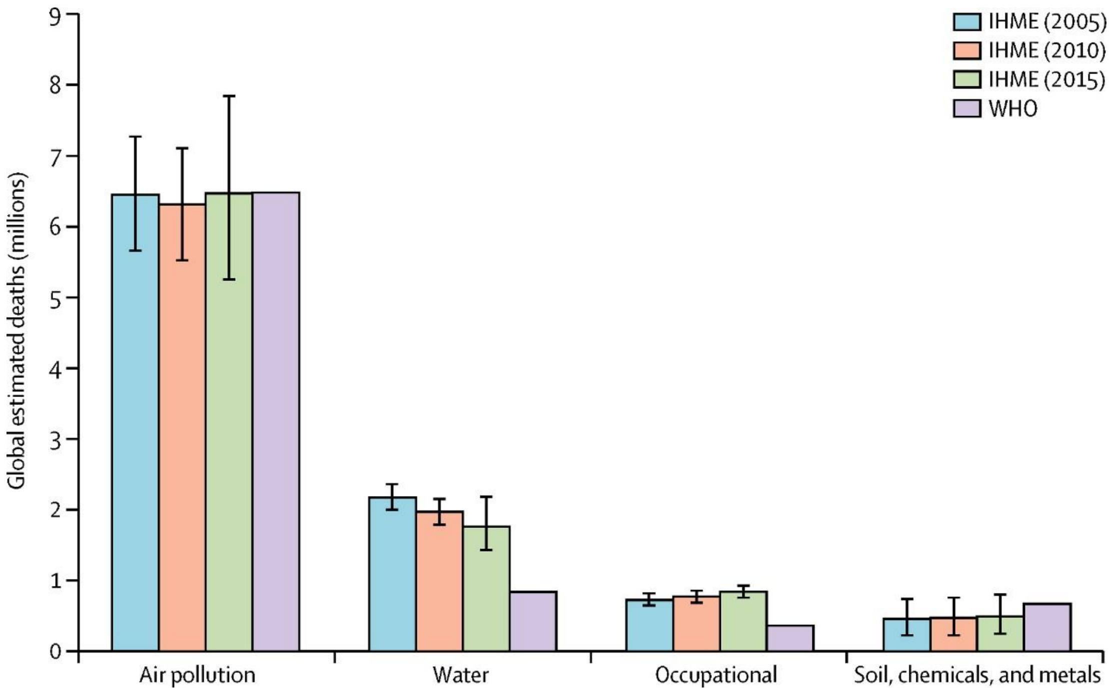
3.4.2 *Air*

The following two sub-sections discuss the health impacts associated with air pollution and the current trends of those health impacts.

Health impacts

Air pollution is one of the greatest public health concerns related to non-communicable disease. An estimated 3.3 million premature deaths worldwide per year have been attributed to outdoor air pollution with the particulate fraction playing a major role. Respiratory health effects are among the primary concerns, with asthma accounting for a large proportion (Meldrum et al., 2017). Compared to water, occupational and soil, chemicals and metals, mortality associated with exposure to air pollution is significantly higher (Figure 6).

Figure 6: Global estimated deaths (millions) by pollution risk factor, 2005-15 (Using data from the GBD study and WHO IHME=Institute for Health Metrics and Evaluation.) Source: (Landrigan et al., 2017)



Air pollution increases the risk of various health problems (including respiratory diseases but also lung cancer and cardiovascular diseases, with children and older people being particularly vulnerable (OECD, 2016). Globally, ambient air pollution is estimated to cause 13% of cardiovascular diseases (CVDs); about 25% of lung cancer deaths are attributable to ambient air pollution; 9% chronic obstructive pulmonary disease (COPD) attributable to ambient air pollution; ambient air pollution can also lead to the development of, and increased morbidity from, asthma (WHO, 2017).

Of the total outdoor air pollution-related premature deaths, 57% are attributed to ischaemic heart disease (IHD) and stroke, 20% to chronic obstructive pulmonary disease, 16% acute lower respiratory infections and 7% to lung cancer. Thus, CVD represents the largest impact of air pollution (Fisher et al., 2017). Epidemiological studies have further linked exposure to ambient air pollution with multiple other health outcomes throughout the life course, including adverse birth and pregnancy outcomes, cardio-metabolic diseases and cognitive impairment, although the quantitative impact of these have yet to be more accurately estimated (Fisher et al., 2017).

Short- and long-term exposures to many pollutants in the ambient air have been associated with increased incidence, morbidity and mortality from CVDs. Particulate matter (PM), especially fine PM ($PM_{2.5}$), has so far been used as the proxy marker for the hazardous effects of air pollution in global analyses. $PM_{2.5}$ concentrations in ambient air have been associated with increased risk of IHD and stroke (and heart failure, as well, which is a sequela of a number of CVDs) (Tzoulaki et al., 2016).

Cohen et al. (2017) estimated the burden attributable to $PM_{2.5}$ for IHD, cerebrovascular disease (ischaemic stroke and haemorrhagic stroke), lung cancer, COPD, and lower respiratory infections (LRI), and the burden attributable to ozone for COPD. Evidence linking these diseases with exposure to ambient air pollution was judged to be consistent with a causal relationship on the basis of criteria specified for Global Burden of Disease study (GBD) risk factors. Long-term exposure to $PM_{2.5}$ contributed to 4.2 million (95% UI 3.7 million to 4.8 million) deaths and to a loss of 103.1 million (90.8 million to 115.1 million) DALYs in 2015, representing 7.6% of total global deaths and 4.2% of global DALYs, which is an increase from 1990. In 2015, ambient $PM_{2.5}$ was the fifth-ranked risk factor for global deaths and sixth-ranked risk factor for DALYs among the risk factors included in GBD 2015. DALYs attributable to long-term exposure to $PM_{2.5}$ consisted of 99.2 million (95% UI 87.7 million to 111.0 million) years of life lost and 3.9 million (2.6 million to 5.2 million) years lived with disability in 2015. Mortality from cardiovascular disease (IHD and cerebrovascular disease) accounted for most deaths and DALYs attributable to ambient $PM_{2.5}$ air pollution. Ambient $PM_{2.5}$ air pollution contributed to 17.1% of IHD, 14.2% of cerebrovascular disease, 16.5% of lung cancer, 24.7% of LRI, and 27.1% of COPD mortality in 2015 according to GBD. Exposure to ozone contributed to 254,000 (95% UI 97,000–422,000) deaths globally and a loss of 4.1 million (1.6 million to 6.8 million) DALYs from COPD in 2015. In 2015, ambient ozone was the 34th-ranked risk factor for global deaths and 42nd-ranked risk factor for DALYs among the 79 risk factors assessed in GBD 2015. Exposure to ozone contributed to an estimated 8.0% (95% UI 3.0–13.3) of global COPD mortality in 2015, with China, India, and the USA experiencing some of the highest mortality rates. The ozone-attributable COPD mortality rate increased in many countries from 1990 to 2015. Global deaths and DALYs attributable to ozone exposure increased from 1990 to 2015, as a result of increases in both levels of ozone and COPD mortality (Cohen et al., 2017).

Landrigan et al.'s (2017) Lancet Commission on pollution and health gives an excellent overview of current health impacts relating to air pollution exposure. $PM_{2.5}$ is the best studied form of air pollution and is linked to a wide range of diseases in several organ systems. Specific causal associations have been established between $PM_{2.5}$ pollution and myocardial infarction, hyper-tension, congestive heart failure, arrhythmias, and cardiovascular mortality. Causal associations have also been established between $PM_{2.5}$ pollution and COPD and lung cancer. The International Agency for Research on Cancer (IARC) has reported that airborne particulate matter and ambient air pollution are proven group 1 human carcinogens.

Fine particulate air pollution is associated with several risk factors for cardiovascular disease, including: hypertension, increased serum lipid concentrations, accelerated progression of atherosclerosis, increased prevalence of cardiac arrhythmias, increased numbers of visits to emergency departments for cardiac conditions, increased risk of acute myocardial infarction, and increased mortality from cardiovascular disease and stroke. Clinical and experimental studies suggest that fine airborne particles increase risk of cardiovascular disease by inducing atherosclerosis, increasing oxidative stress, increasing insulin resistance, promoting endothelial dysfunction, and enhancing propensity to coagulation (Landrigan et al., 2017).

Emerging evidence suggests that additional causal associations may exist between $PM_{2.5}$ pollution and several highly prevalent NCDs. These include diabetes, decreased cognitive function, attention-deficit or hyperactivity disorder and autism in children, and neurodegenerative disease, including dementia, in adults. $PM_{2.5}$ pollution may also be linked to increased occurrence of premature birth and low birthweight (Landrigan et al., 2017).

Some studies have reported an association between ambient air pollution and increased risk of sudden infant death syndrome. These associations are not yet firmly established, and the burden of disease associated with them has not yet been quantified. Respiratory disease, CVD, stroke, and cancer account for the largest proportion of the DALYs from pollution-related disease. Air pollution is responsible for half of the DALYs associated with lower respiratory tract infections and COPD worldwide, and for a quarter of the DALYs resulting from IHD and stroke. Globally, 24% of the DALYs associated with cancers of the trachea, bronchus, and lungs are attributed to air pollution. The proportions of DALYs linked to each of these non-communicable diseases are higher in low-income and middle-income countries than in high-income countries (Landrigan et al., 2017).

In Europe, air pollution is the single largest environmental health risk. Heart disease and stroke are the most common reasons for premature death attributable to air pollution and are responsible for 80% of cases, followed by lung diseases and lung cancer. Air pollution increases the incidence of a wide range of diseases (e.g. respiratory and cardiovascular diseases and cancer), with both long- and short-term health effects, including at levels below the existing World Health Organization (WHO) guideline values (EEA, 2017).

Specific vulnerabilities are also observed in the literature, an aspect picked up in section **Error! Reference source not found.**. Negative health effects of air pollution exposure include CVDs, respiratory health problems (asthma, lung damage), eye and throat irritation, high blood pressure, brain and kidney damage, neurological disorders and cancer, amongst others. The extent to which these effects occur depends on the duration and accumulation of exposure, but also to personal characteristics. For instance, the elderly, infants or pregnant women are more sensitive to certain pollutants (van Wee and Ettema, 2016).

Extremely heavy pollutant loads frequently give rise to disturbances and diseases of the respiratory tract in children and adults (e.g. acute breathing difficulties, chronic coughing and expectoration, bronchitis and chronic bronchitis, and respiratory infections). In the alveoli, respiration and blood circulation are very closely intertwined, both anatomically and functionally. So disturbances to one system, e.g. an inflammation of the respiratory tract, may also affect the other, in this case the cardiovascular system. In people who are already ill, air pollution imposes a further burden. The higher the air pollutant load, the briefer the respite between episodes (Swiss Federal Office for the Environment, 2012).

Air pollution levels have been linked with asthmatic symptoms, a decrease in lung function, and increased emergency room visits and hospitalizations. The lag time amounts to 24 hours following the acute episode. In children with moderate persistent asthma, the occurrence of symptoms and the decrease in lung function are more pronounced in those patients who do not follow a maintenance therapy (Gautier and Charpin, 2017).

Evidence for an association between air pollution and in particular traffic derived material, and asthma has accumulated over the last decades, with systematic reviews continuing to build a weight of evidence for direct causal effects. A separate series of studies examining air pollutant exposure in a Finnish adult asthmatic population found an association between a larger particle number and decreased lung function (PEF), which they suggested could be attributed to the level of ultrafine particles (UFPs). In this study significant associations between higher levels of atmospheric pollutants and reduced lung function were observed for UFP and carbon content, which were not observed to the same extent for $PM_{2.5}$ or NO_2 levels. These effects were more pronounced in those volunteers with moderate versus mild asthma. There is evidence that diesel exhaust particle levels are associated with exacerbation of pre-existing asthma and more recently evidence also points towards a direct impact on sensitisation and respiratory effects in early life (Meldrum et al., 2017). Living close to a busy road increases a child's risk of developing asthma and urban planning needs to consider proximity of road traffic to housing/schools (European Lung Foundation and European Respiratory Society, 2013).

Air pollution is nowadays considered to be a new risk factor for hypertension (HTN). Even brief exposure to air pollution might trigger a rapid and significant increase of blood pressure. Elderly and those with comorbidities are at higher risk for air pollution–mediated cardiovascular events. Air pollution is linked to cardiovascular toxicity and as a triggering factor potentially induces HTN mainly due to autonomic nervous system imbalance and subsequent vasoconstriction. Furthermore, patient susceptibility might play an important role in determining the exact hemodynamic responses. The major strategy in decreasing the harmful effects of air pollution is the reduction of air pollutants themselves (Sanidas et al., 2017).

Currently, it has been accepted that particulate matter can contribute to autoimmunity by complex interactions between genetic, environmental, and epigenetic factors. However, the exact molecular mechanisms by which chemicals contained in air pollution affect autoimmunity are still unknown. Particulate matter present in air pollution can induce oxidative stress and cell death, by both apoptosis and necrosis of human cells leading to aggravation of chronic inflammation, i.e. the tissue damaging reaction observed in autoimmune diseases. Therefore, identification of strong inducers of oxidative stress among components of PM seems to be crucial for their neutralisation and elimination from the ambient environment (Gawda et al., 2017).

The evidence is now overwhelming that primary and secondary small and ultrafine particles (PM_{10}, $PM_{2.5}$ and $PM_{0.1}$) in particular, are linked to increased all-cause mortality (29,000 deaths each year in the UK) and especially deaths from cardiovascular and respiratory disease. Recent research shows that oxides of nitrogen (NOx: NO, NO_2 and N_2O_4) and specifically NO_2 emitted in vehicle exhaust are not as benign as previously thought, increasing the number of UK associated deaths by up to 40,000 each year (Holgate, 2017).

Air pollution has adverse effects across the life course – from conception to old age. Air pollution impairs overall foetal growth, especially lung growth; this persists across childhood, increases the risks of developing new asthma, which might not occur in its absence, and affects the heart and lungs throughout life by direct toxicity and via epigenetic mechanisms that mediate gene/environmental interactions. Beyond respiratory and cardiovascular disease, air pollution has adverse impacts on the development of impaired cognition, type 2 diabetes, cancers, skin aging, and even acts as a risk factor for obesity. New evidence has also become known on the adverse effects of pollution on neurodevelopment. More recent research has revealed that air pollution increases the risk of stroke by a factor of one third (Holgate, 2017).

In a systematic review, Checa Vizcaíno, González-Comadran and Jacquemin (2016) found a small significant association between elevated air pollution and diminished fertility outcomes in the exposed population, including rates of live births, fertility, and miscarriage. These results indicate that lower fertility rates may be linked to traffic-related air pollution. Since the last published systematic review (in 2015) that explored fertility outcomes in relation to exposure to air pollutants, two new articles have been published in the same field of research. This new research shows that human reproduction is influenced by coarse PM and distance to the roadway (Checa Vizcaíno, González-Comadran and Jacquemin, 2016).

Clifford et al.'s (2016) systematic review found evidence suggestive of a relationship between air pollution exposure and cognitive parameters throughout the lifespan. In children, poorer performance was seen across several cognitive measures including neurodevelopment, intelligence and memory in those exposed to higher levels of air pollution. In utero exposure to air pollution was also associated with intelligence and neurodevelopment around ages 3–5 years. Consistent with previous studies with other types of environmental toxins, there is some evidence that boys are more affected by air pollution than are girls, though this requires confirmation from further research. In adults, accelerated cognitive aging was seen on tests of visuo-motor abilities, memory and learning in those exposed to higher levels of air pollution (Clifford et al., 2016). There is at least moderate evidence implicating air pollution as a risk factor on dementia (Killin et al., 2016).

Urban and transport planning have large impacts on public health (Nieuwenhuijsen et al., 2017). Air pollution exposure from urban transport emissions are related to premature mortality, e.g. 184,000 deaths globally, including 91,000 deaths from ischemic heart disease, 59,000 deaths from stroke, and 34,000 deaths from LRIs, COPD, and lung cancer. There is also evidence that urban transport emissions also contribute to lung cancer incidence; CVD; asthma; reduced lung function in children; reduced cognitive function; respiratory infections during early childhood; low birth weight; premature birth; diabetes; and obesity (Khreis, May and Nieuwenhuijsen, 2017).

In cities, environmental exposures such as air pollution, temperature, and noise have been associated with adverse health effects, while ultraviolet radiation (UVR) and green space have been associated with both positive and negative health effects, and are therefore important to measure and control. In a novel approach, Dadvand and colleagues extended previous analyses, suggesting that proximity to major roads is a risk for term low birth weight. They considered the mediating roles of air pollution, noise, heat, and road-adjacent trees in a cohort of births in Barcelona. Their analysis suggested that air pollution and heat jointly account for one-third of the measured association between road proximity and low birth weight. More than in prior analyses, they considered multiple potential exposures related to urban form (Nieuwenhuijsen, 2016).

Long-term exposures to road traffic noise and ambient air pollution were associated with blood biochemistry, providing a possible link between road traffic noise/air pollution and cardio-metabolic disease risk (Cai et al., 2017). Taken together, there is a growing body of evidence that the environmental exposure to traffic noise and air pollution can cause CVD, including coronary heart disease, myocardial infarction, arterial hypertension, heart failure, arrhythmia, and stroke (Münzel et al., 2017).

The net effect of individual pollutants on population health has been widely reported at regional scales, but little is known about the combined direct health effects of air pollution, pollen and temperature. This makes quantifying the resulting health impacts particularly challenging (Salmond et al., 2016).

Consistent with existing studies, when using detailed local data, Orru et al. (2016) found a significantly negative relationship between air pollution and individual self-reported life satisfaction. The effect of PM_{10} remained significant in regressions run for both, with and without controlling for health status. This suggests that much of the negative impact of PM_{10} on life satisfaction may be a direct effect not captured by the health variables. The results show that even relatively low levels of air pollution may lower subjective well-being assessments due to the possible effects of elevated physical stress, irritation and annoyance. These results highlight the significance of air pollution abatement strategies for maintaining health as well as emotional well-being (Orru et al., 2016).

There is evidence to indicate that exercise in urban settings promotes health despite exposure to air pollution. Urban green spaces reduce heat stress and exposure to air pollution and noise (Fisher et al., 2017).

Health impact trends

Associated with the continuing increase in global concentrations of pollutants, particularly in developing countries in south-east Asia, there is an increasing trend in global mortality and morbidity. Global mortality due to ambient $PM_{2.5}$ increased from 1990 to 2015. Attributable deaths rose from 3.5 million (95% uncertainty interval (UI) 3.0 million to 4.0 million) in 1990 to 3.8 million (3.3 million to 4.3 million) in 2000, and 4.2 million (3.7 million to 4.8 million) in 2015, a 20% increase. However, age-standardised $PM_{2.5}$ mortality rates decreased from 65.6 per 100,000 people (95% UI 56.9–74.9) in 1990 to 57.5 per 100,000 people (50.2–64.8) in 2015. Trends in $PM_{2.5}$-attributable mortality among countries largely reflect changes in $PM_{2.5}$-attributable mortality from cardiovascular disease. In World Bank high-income countries, the all-age proportion of $PM_{2.5}$-attributable cardiovascular disease deaths decreased from 10.0% to 8.1% as a result of reductions in cardiovascular mortality and decreasing levels of $PM_{2.5}$. By contrast, in World Bank low-income countries, it increased from 13.1% to 13.2%, and in lower-middle-income countries from 15.9% to 16.5%, between 1990 and 2015. Trends in $PM_{2.5}$-attributable mortality at the global and national levels reflect the influence not only of changing air quality, but also of demography and underlying mortality rates (Cohen et al. 2017).

The economic cost of premature deaths from ambient particulate matter pollution and household air pollution was estimated to amount to US$ 1.5 trillion in the European Union in 2010 (WHO, 2016). In 41 European countries listed in the EEA (2017) report, 428,000 premature deaths are attributed to $PM_{2.5}$ exposure; 78 000 premature deaths are attributed to NO_2; and 14,400 premature deaths to O_3 exposure. In the EU-28, the premature deaths attributed to $PM_{2.5}$, NO_2 and O_3 exposure are 399,000, 75,000, and 13,600, respectively. When considering years of life lost (YLL) per 100,000 inhabitants, the largest impacts for $PM_{2.5}$ are observed in the central and eastern European countries where the highest concentrations are also observed, i.e. Bulgaria, Kosovo under UNSCR 1244/99, the former Yugoslav Republic of Macedonia, Serbia, Poland and Hungary. The lowest relative impacts are found in the countries at the northern and north-western edges of Europe: Iceland, Norway, Ireland, Sweden and Finland. For NO_2, the highest rates of YLL per 100,000 inhabitants are found in Italy, the United Kingdom, Serbia, Belgium and Germany and for $O_{3,}$ Greece, Italy, Malta, Slovenia and Croatia have the highest rates of YLL per 100,000 inhabitants (EEA, 2017).

The increase in the absolute number of deaths and disability-adjusted life years (DALYs) attributable to pollution reflects an increased population size, an aging population, and increased levels of air pollution in low-income and middle-income countries. An analysis of future trends in mortality associated with ambient $PM_{2.5}$ air pollution finds that, under a “business as usual scenario”, in which it is assumed that no new pollution controls will be put into place, the numbers of deaths due to pollution will rise over the next three decades, with sharpest increases in the cities of south and east Asia. These trends are projected to produce a more than 50% increase in mortality related to ambient air pollution, from 4.2 million deaths in 2015 to 6.6 million deaths in 2050 (95% CI 3.4 million–9.3 million). These projections are corroborated by an analysis of the health effects of coal combustion in China. Population aging is a major contributor to these projections of growth and absolute increased numbers of deaths from pollution-related disease (Landrigan et al., 2017).

3.5 Key sources of noise and air pollution

Road traffic is the most significant source of both noise and air pollution (mainly NOx but also PM), particularly in urban areas where exposure is highest by virtue of the relative population density. Railway, aircraft and industry are also significant noise sources. Commercial, institutional and households are the main sources of particulate matter (PM_{10} and $PM_{2.5}$), followed by industry and agriculture, while energy production dominates emissions of sulphur oxides (SOx). Shipping can also be a significant source of NOx, SO_2 and $PM_{2.5}$, whereas agriculture is the main source of ammonia (NH_3) leading to increasing secondary $PM_{2.5}$.

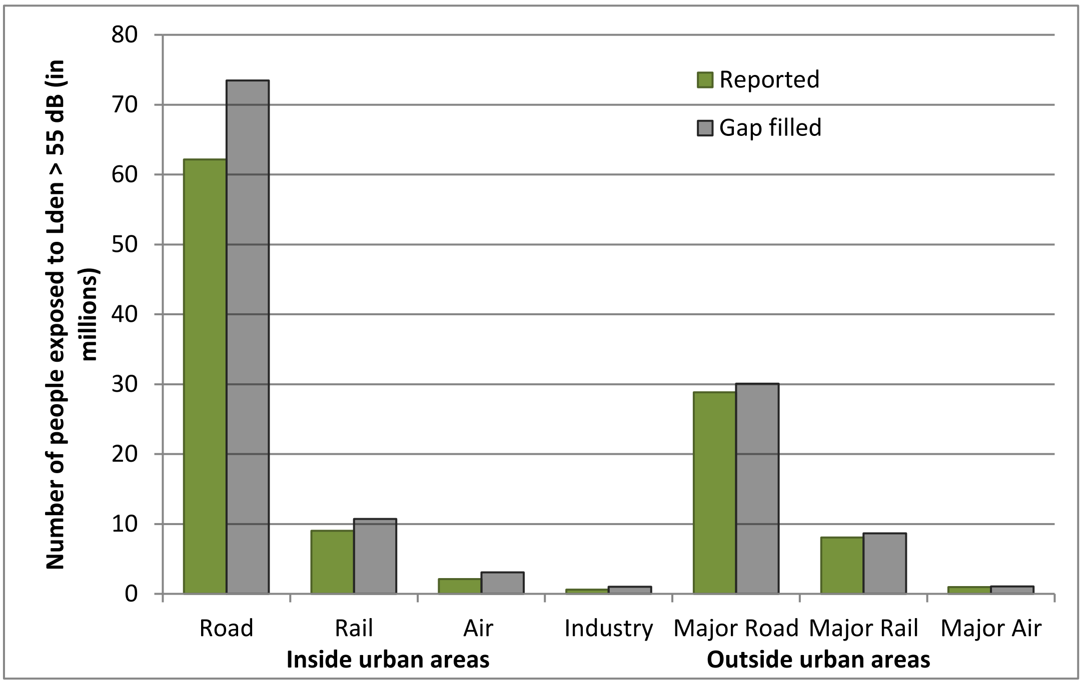
3.5.1 *Noise*

Related to types (section 3.4.1), sources of noise pollution have not changed since the SEP report[26] (Table 1).

Road traffic noise, both inside and outside urban areas, is still the most dominant source affecting human exposure above the action levels defined by the END, with the latest available information reported by member countries (reference year 2012). Estimations based on calculated figures complementing current data reported on noise exposure show that more than 100 million people could actually be exposed to road traffic noise above 55 dB Lden, with more than 32 million exposed to noise levels above 65 dB Lden (Figure 7). Nevertheless, 55 dB Lden and 50 dB Lnight as lower values to be used for the calculation of strategic noise maps might change in view of aligning the analysis to the upcoming new WHO guidelines -based on the latest scientific evidence- and on the conclusions raised by the European Commission in the REFIT evaluation of the Directive 2002/49/EC[27].

[26] http://ec.europa.eu/environment/integration/research/newsalert/pdf/air_noise_pollution_socioeconomic_status_links_IR13_en.pdf (see section 1.3)
[27] http://ec.europa.eu/environment/noise/pdf/staff_working_doc_refit_evaluation_environmental_noise.pdf

Figure 7: Number of people exposed to noise in Europe > 55 dB L_{den} in EEA member countries (2012): reported and estimated data



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

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

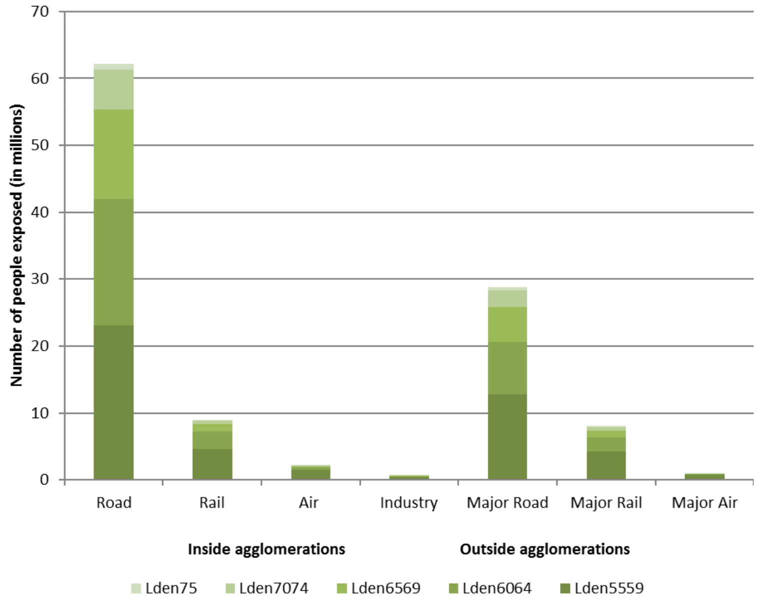
Health risk increases with higher levels of exposure, and noise abatement measures may differ depending on the source and on the specific noise level band being addressed.

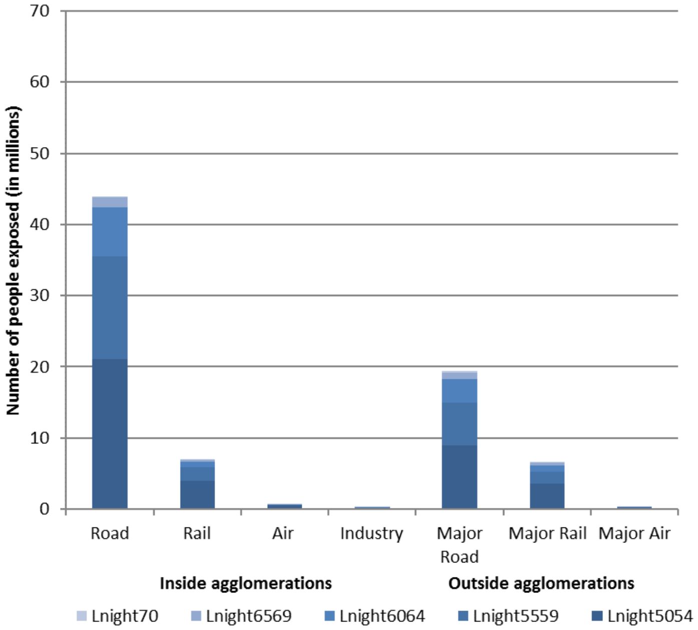
The END requires provision of exposure information in 5 decibel bands for two indicators, to be applied in noise mapping and action planning:

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

The highest percentage of people reported are exposed to the lower decibel band for all noise sources, as observed in the previous assessment (EEA, 2014), and this is still the case with the new data delivered. The major difference between the lower band and the rest of noise bands is still the people exposed to aircraft noise both inside and outside urban areas, while the more balanced distribution among the population exposed to the five noise bands is the exposure to road traffic noise, both inside and outside urban areas; following the same pattern for L_{den} and L_{night} values (Figure 8).

Figure 8: Reported number of people exposed to noise per decibel band in Europe (2012): L_{den} and L_{night}

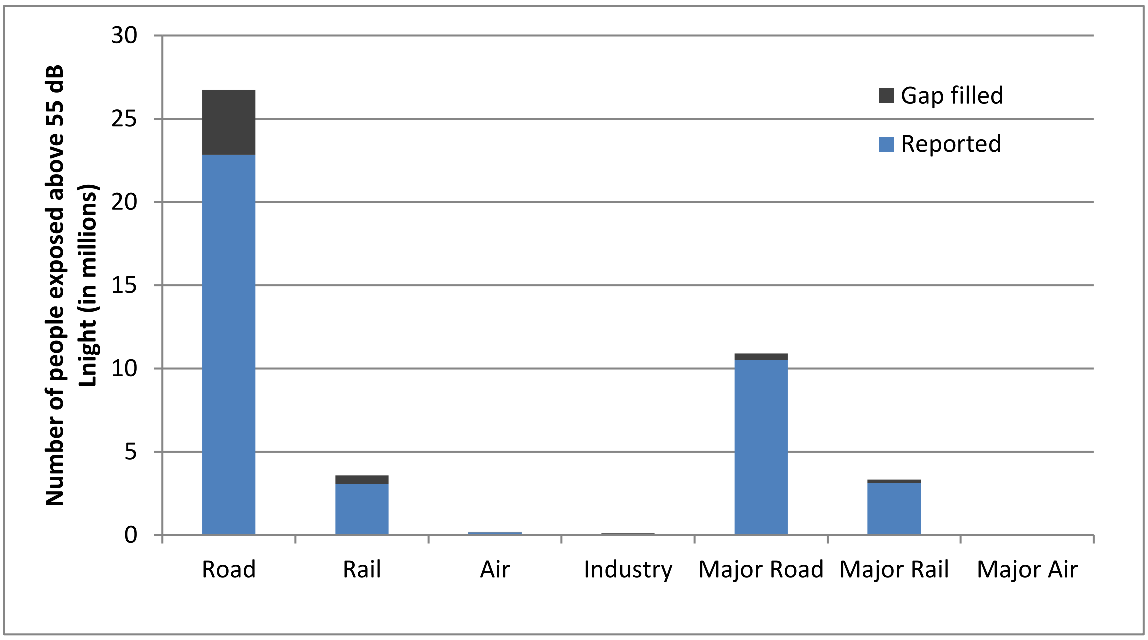




'High noise levels' are defined in the 7th EAP as noise levels above 55 dB L_{den} and 50 dB L_{night}, which are in fact the minimum noise levels at which the END requires the provision of the exposure data in 5 decibel bands.

Although the Environmental Noise Directive Reporting Mechanism (ENDRM) accommodates the reporting of noise mapping exposure assessments in line with the Night Noise Guidelines level of 40 dB L_{night} on voluntary basis, only a few EEA member countries have provided these data.
So focusing on the data being requested by the END, it is estimated that more than 36 million people are exposed to more than 55 dB L_{night} in Europe due to road traffic noise, followed by nearly 7 million people exposed to more than 55 dB L_{night} in Europe due to rail traffic noise and 250,000 people and 100,000 people exposed to air traffic noise and industrial noise inside urban areas respectively (Figure 9).

Figure 9: Number of people exposed to noise in Europe > 55 dB Lnight in EEA member countries (2012): reported and estimated data



Extrapolation to the full European coverage

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

An extrapolation to the full European coverage was carried out focused on exposure to road traffic noise, to serve as input for the health impact assessment.

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

The second step was to estimate the full exposure distribution per decibel for road traffic noise within agglomerations, based on the number of exposed residents in the 5 dB L_{den} categories above 55 dB and the remaining number of inhabitants within the agglomeration in the category below 55 dB L_{den}. More information on the statistical model being used can be found in ETC/ACM Working paper (2016).

In a third step, a methodology was developed to estimate the road noise exposure distribution in areas not covered by the END. This methodology makes use of the association between population density and the noise exposure level. This association has been recognized about 40 years ago (Galloway et al., 1974). By using the relationship between population density and exposure distribution from the Netherlands (RIVM, 2011) and from Switzerland (BAFU, 2015) and subsequently applying it to the rest of countries, an estimated number of people exposed to road traffic noise per each country has been encountered. By adding this information to the number of people exposed to major roads outside agglomerations, almost 230 million people are exposed to road traffic noise above 50 dB L_{den} and 261 million residents are exposed above 40 dB L_{night}.

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

The combination of the different calculations and steps give a total exposed population of 357 million inhabitants above 50 dB L_{den} (of which 206 are exposed above 55 dB L_{den}) and for the night time exposure, a total of 421 million inhabitants are exposed above 40 dB L_{night} due to road traffic noise. Taking into account that the total number of inhabitants in all Europe (EEA 32 member countries being considered, and Macedonia and Montenegro) is estimated to be 525 million people, nearly 7 out of 10 people living in Europe are exposed to noise levels above 50 dB L_{den}, and approximately 4 out of 5 residents are exposed to night noise levels above 40 dB.

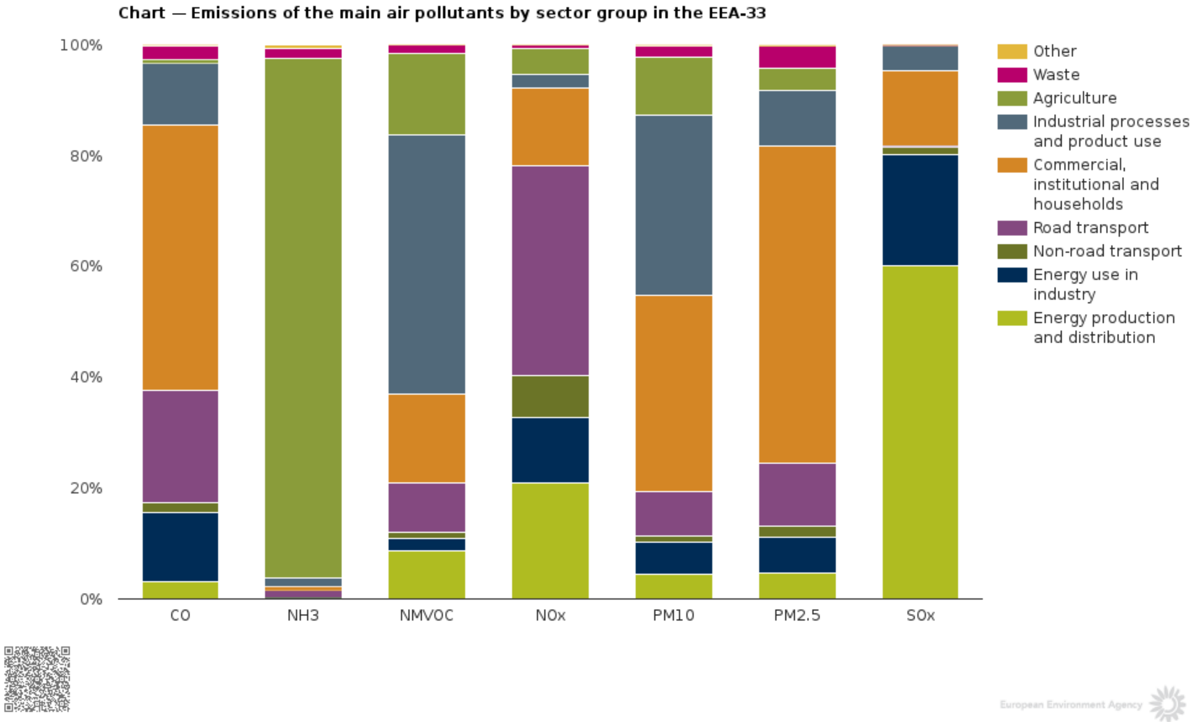
3.5.2 *Air*

Emissions of air pollutants in Europe vary by source (Figure 10). Source contributions have not changed dramatically since the publication of the SEP (2016) report. Collectively ‘commercial, institutional and households’ are the main source of PM_{10} (35.41%) and $PM_{2.5}$ (57.36%) in EEA countries. For PM_{10}, this is followed closely by industry (32.47%), with smaller contributions from agriculture and transport. For $PM_{2.5}$, road transport and industrial processes contribute 11.33% and 9.95% respectively. Energy production (60.08%) dominates emissions of sulphur oxides (SOx). Road transport generates 37.93% NOx emissions in the EEA-33, with energy production and distribution contributing 20.83%, followed by ‘commercial, institutional and households’ (13.93%) and energy use in industry (12%). 93.88% ammonia emissions are from agriculture, which is an increasing source of secondary $PM_{2.5}$.

The recent EU Directive 2016/2284 on the reduction of national emissions of certain atmospheric pollutants, which entered into force on 31 December 2016, sets national reduction commitments for sulphur dioxide, nitrogen oxides, volatile organic compounds, ammonia and fine particulate matter. For any year from 2020 to 2029, emissions of NH_3 across the EU need to be reduced by 6% (compared with 2005), while for any year from 2030 the reduction commitment is set at 19%. These reductions in NH_3 emissions are not very stringent, especially when compared to the reduction commitments of sulphur dioxide (by 59% for 2020, 79% for 2030) and nitrogen oxides (42% by 2020, 63% by 2030), and also considering the efficiency of NH_3 emission reduction in reducing $PM_{2.5}$. Abatement of ammonia is a key factor in reducing aerosol formation, and it is relatively more effective in achieving $PM_{2.5}$ reductions compared to the abatement of sulphur and nitrogen oxides. Therefore, all precursor gases should be reduced at least equivalently to achieve the maximum potential reduction in $PM_{2.5}$ concentrations (Giannadaki et al., 2018).

Using the Netherlands as an example, Dutch inventories show that the contribution of agricultural sources to the national ammonia emissions was 85%. Agricultural emissions decreased by 70% since 1990, mainly due to mandatory low emission application of manure since 1991. The contribution of emission from synthetic fertiliser in 2013 was 13%. In spite of the 50% reduction of synthetic fertiliser use, the 2013 emission of 13.6 kton NH_3 was close to the level in 1990 due to a gradual replacement of calcium ammonium nitrate by urea type fertiliser. In the same period, however, measured ammonia concentrations only slightly decreased. There are several explanations for this discrepancy of trends. First, the decrease of emissions might have been overestimated due to lack of compliance with regulations for ammonia emissions from housing and during manure application. Second, the number of sites where ammonia concentrations are measured might be too low to capture the high spatial variability of ammonia concentrations typical for agricultural emissions. Finally, NH_3 concentrations may have increased because of the strong decrease of SO_2 in response to acidification policies, which reduces formation and deposition of airborne ammonia aerosols (Van Grinsven, Tiktak and Rougoor, 2016).

Figure 10: Emissions of the main air pollutants by sector group in the EEA-33 (Source: EEA, 2017[28]. Last modified 07 Sep 2017)



In terms of exposure, road traffic is the main source of air pollution (NO_2 and PM_{10}) in urban areas, where population density is highest and therefore more individuals are at risk (Porta et al., 2016; Russell-Jones, 2017; Westergaard et al., 2017; Kumar and Goel, 2016; Filippini et al., 2016; Rancière et al., 2017; Holgate, 2017; Forns et al., 2017; Tzivian et al., 2016; Meldrum et al., 2017; Oliveira et al., 2017; Matejicek, 2016; Carey et al., 2016). This is illustrated in the following studies.

In Seville, chemical composition data showed that PM is generated in large proportion by vehicle traffic (Pb, Cu, Zn, Ba, Ti and Mn), and this should consequently be considered in air pollution mitigation strategies (Fernández-Camacho, de la Rosa and Sánchez de la Campa, 2016).

Heavy vehicles are clearly an important factor in urban air pollution. Whilst increased buses might be desirable for many social and environmental reasons it is clear that this has to be in conjunction with investment in cleaner emissions technologies such as the successful installation of low NO_2 SCRT on some of London's buses. Greater management of HGVs is also needed to ensure that increased numbers do not offset benefits from emissions abatement and to control the increase in coarse PM. A greater

[28] https://www.eea.europa.eu/data-and-maps/daviz/share-of-eea-33-emissions-3#tab-chart_1

investigation of sources of PM_{coarse}, the factors which control emission rates and options for managing them is needed (Font and Fuller, 2016).

The main problem is diesel. The UK, along with much of Europe, has adopted diesel as the main fuel for private cars. Before 2000 less than 10% of new cars sold in the UK were diesel. Now the figure is over 50%. Furthermore, the amount of nitrogen dioxide (NO_2) emitted by most diesel cars on the road is 4-5 times the EU limits allowed in laboratory tests. Illegal defeat devices installed by Volkswagen enabled NO_2 emissions up to 40 times the EU limit (Russell-Jones, 2016).

Non-exhaust emissions can also be problematic. In Rome, Badaloni et al. (2017) found tracers of non-tailpipe traffic emissions such as tyre and brake wear and mixed oil burning/industry. Munker et al. (2016) found the influence of traffic emissions on the excretion of rhodium, whereas Khreis, May and Nieuwenhuijsen (2017) identified motor vehicle exhaust and non-exhaust emissions, secondary air pollutants formation, underground, metro, rail exposures.

According to Thornes et al. (2017) air quality at the enclosed railway stations considered does not meet European air quality standards for nitrogen dioxide and particulate pollution. Currently, occupational health standards are used to determine air quality in these locations. This is probably not a problem for well-ventilated outdoor railway stations. However, for enclosed railway stations, which are effectively 'indoors', public health guidelines could be used and it is likely that the air quality measured by the daily air quality index in enclosed railway stations could be classed as 'very high' on a daily basis. It is important to consider air pollution levels and public health effects for commuters using enclosed railway stations as well as other forms of commuter transport into cities to avoid worsening exposure levels through promotion of rail as an alternative to single-occupancy vehicles (Thornes et al., 2017).

In some urban areas, particularly in the colder regions of Europe, domestic combustion is also a significant source. Epidemiological studies have shown that exposure to PAHs is correlated with increased incidence of cancer. Carcinogenicity is associated mainly with metabolites that are formed during metabolic degradation of these substances in exposed organism. In a study in the Czech Republic monohydroxylated PAHs (OH-PAHs), the major metabolites excreted into urine, were determined in 531 urine samples collected from mothers and their newborns from two localities. Results showed that the amounts of ΣOH-PAHs in newborns' urine samples from highly industrialized Karvina in the winter season were 1.5 times higher than in the summer season collected in the same locality and 3.3 times higher when compared with the less polluted locality of Ceske Budejovice. This was probably due to the smog situation resulting from heavy industry and local heating (Urbancova et al., 2017). The major contributors to the high CO levels in Poland are non-industrial combustion plants (especially households), followed by road transport and industry, with the first one in the definite lead. The vast majority of industrial plants of significant nuisance to air quality do not possess pollutant reduction systems. Silesia, with the highest number of plants contributing to significant nuisance to air quality and the highest population density is the adverse leader in CO emission among Polish geographical regions. However, in 2013 the Krakow agglomeration had the highest annual mean concentration of CO among Polish agglomerations and cities. This is mostly due to two reasons: geographic position (location of the land is the cause of reduced air circulation, which leads to the pollutant concentration) and high number of 19th century tiled stoves in apartments in the historical Old Town of the city (Maga et al., 2017).

Kasurinen et al. (2017) also investigated toxicity of combustion of birch, beech, and spruce logs as common fuel types in central and northern Europe. A bottom-up approach for collecting citizen's localized insights based on public participation GIS was designed and carried out in Oslo and Akershus, two Norwegian regions, aiming at improving the understanding of wood burning for residential heating in urban areas. Their study shows differences between the highly populated urban areas, i.e. Oslo, and the urban-rural combined area, i.e. Akershus, as fuelwood consumption is reported to be higher in the latter. In spite of this difference, the results show the importance of wood burning as a heating source in urban areas, and therefore of the subsequent particle emissions. In Oslo for instance, 46% of the fuelwood is used in apartments. Wood consumption from the sampled population reach around 200 tonnes of fuelwood in one winter season (i.e. November 2015 to February 2016). Wood consumption is scaled to different administrative areas based on the information provided by citizens on use of fuelwood for residential heating and type of wood stove. Wood consumption is estimated to be three times higher than available official data in urban areas, whereas for urban-rural combined areas is estimated to be at the similar level. The study shows that the characterization of human activity that results in pollutant emissions in highly populated urban areas is still a challenge. The geographical distribution of wood stoves shows that the share of new stoves (≈53%), which are cleaner and more efficient, is almost the same for both regions. This result is unexpected as there have been economic incentives for shifting from older to newer appliances in Oslo city since 1998, and the results seem to show a low penetration in the urban environment comparing with areas without economic incentives (López-Aparicio et al., 2017).

In Athens, black carbon (BC) and long-term CO measurements were taken to evaluate the increasing role of biomass combustion. CO emitted by wood burning was found to contribute almost 50% to the total CO emissions during night time (16:00–5:00), suggesting that emissions from biomass combustion have gained an increasing role in atmospheric pollution levels (Gratsea et al., 2017).
Globally, household air pollution from solid fuel use was responsible for 2.8 million (95% UI 2.2 million to 3·6 million) deaths and 85.6 million (66.7 million to 106.1 million) DALYs in 2015. Together, ambient and household air pollution were estimated to have caused 6.4 million (5.7 million to 7.3 million) deaths in 2015 (Cohen at al., 2017). Fossil fuel combustion in high-income and middle-income countries, and biomass burning in inefficient cookstoves, open fires, agricultural burns, forest burning, and obsolete brick kilns in low-income countries accounts for 85% of airborne particulate pollution and for almost all pollution by oxides of sulphur and nitrogen. Fuel combustion is the major source of greenhouse gases and short-lived climate pollutants that are the main anthropogenic drivers of global climate change (Landrigan et al., 2017).

Ports can also have negative air quality effects caused by their infrastructure and related transport activities, including the presence of trucks, vessels, and industrial sectors with air pollution (Schipper, Vreugdenhil and de Jong, 2017). A study of 18 ports of Greece identified that in terms of the total in-port inventory for cruise shipping, NOx is dominant (2487.9 tons), followed by SO_2 and $PM_{2.5}$ (995.3 and 121.3 tons respectively), while the total emissions of greenhouse gases (GHG) were 124,767.8 tons CO_2-eq (for CO_2, N_2O, and CH_4). Emissions during hoteling corresponded to 89.2% of total, and significantly outweighed those produced during the vessels' manoeuvring activities (10.8% of total). Seasonality was found to play a major role, as summer emissions and associated impacts are more profound. In almost all major ports, an extension of the tourism season to October and November has been observed, leading to increased autumn emissions. (Papaefthimiou, Maragkogianni and Andriosopoulos, 2016).

Sarigiannis et al., (2017) also found major PM sources in Greece were ship emissions during summer and biomass burning during winter.

Municipal solid waste incinerator and waste treatment plants have also been identified as key sources (Gallego et al., 2016; Zubero et al. 2017) generating significant quantities of toxic metals to the air by the incineration of waste, as well as by the combustion of coal and oil (Nedellec and Rabl, 2016). García-Pérez et al.'s (2016a) study analysed the risk of rare tumours in children in the vicinity of environmental pollution sources, as industrial plants and urban areas, according to different industrial groups and groups of carcinogens and other toxic pollutants. Results did not show increased risks with residential proximity to environmental pollution sources, but did find isolated statistical associations between retinoblastoma and proximity to industries involved in glass and mineral fibres and organic chemical industries (García-Pérez et al., 2016a). Another study suggested a possible increased risk of neuroblastoma among children living in the intersection between industrial and urban areas and, specifically, near mines, metal industries, explosives and pyrotechnics, and urban waste-water treatment plants. These findings support the need for more detailed exposure assessment and health risk analysis of certain toxic substances released by these types of industries (García-Pérez et al., 2016b).

Further research provides some epidemiological evidence that living in the proximity of industrial areas and agricultural crops may be a risk factor for childhood renal cancer. Specifically, children living near plants involved in the metal industry, glass and mineral fibres, ceramic, organic chemical industry, hazardous waste, urban waste-water treatment plants, and food and beverage sector showed an increased risk. In addition, analysis by group of substances showed a statistically significant excess risk of childhood renal tumours in the proximity of installations releasing carcinogens, pesticides, persistent organic pollutants, solvents, non-halogenated phenolic chemicals, polycyclic aromatic chemicals, metals, and volatile organic compounds (García-Pérez et al., 2016c).

Agriculture as an exposure source was also studied by Cantuaria, Løfstrøm and Blanes-Vidal (2017) and found that short-term NH_3 exposures are superior in predicting livestock odour annoyance. Landrigan et al. (2017) also highlighted the presence of glyphosate widely detected in air and water in agricultural areas, as well as glyphosate residues detected in commonly consumed foods. Epidemiological studies of agricultural workers who were exposed occupationally to glyphosate and other herbicides have found evidence for increased occurrence of non-Hodgkin lymphoma. Toxicological studies of experimental animals exposed to glyphosate show strong evidence of dose-related carcinogenicity at several anatomical sites, including renal tubule carcinoma and haemangiosarcoma. On the basis of these findings, the International Agency for Research on Cancer has determined that glyphosate is a "probable human carcinogen"; however, this finding is contested by glyphosate's manufacturer (Landrigan et al., 2017).

In addition to the anthropogenic sources highlighted above, these exposures are often complicated by the additional presence of natural sources. PM_{10} from a suburban site in the northwest of Spain was assessed by Megido et al. (2017) and found six relevant sources road traffic, mineral dust and sulphates, marine aerosol, steelworks, combustion and secondary aerosol. Díaz et al. (2017) has also studied Saharan dust intrusions, while Hlodversdottir et al. (2016) investigated exposures to volcanic eruption in Icelandic residents. Vegetation fires can also release substantial quantities of fine particles ($PM_{2.5}$), which are harmful to health (Kollanus et al., 2017).

Furthermore, natural and anthropogenic sources can be further exacerbated by meteorological conditions. Matthaios, Triantafyllou and Koutrakis (2017) investigated extreme PM_{10} air pollution episodes in five characteristic areas of Greece during the years of 2009, 2010, and 2011, based on PM_{10} concentration data collected from 18 monitoring stations. They identified 14 extreme PM_{10} air pollution episodes (i.e. successive days during which the mean PM_{10} concentration in all five of the study areas exceeded the EU 24-hr PM_{10} legislative limits) taking place over a total of 49 days classified into two main categories: (1) Local Source Impact (LSI, 53%) and (2) African Dust Impact (ADI, 47%), with average intensities of 1.3 and 2.0, respectively. All the above extreme PM_{10} air pollution episodes were the result of specific synoptic prevailing conditions, and the contribution to PM_{10} concentration of the ADI extreme episodes was 1.10–3.10 times higher than the contribution of the LSI extreme episodes (Matthaios, Triantafyllou and Koutrakis, 2017)

4 Impacts of socioeconomic status on vulnerability to exposure to noise and air pollution

In this section we will examine:

1. Factors that help determine the exposure of different socioeconomic groups.
2. Reflections on how people on higher incomes can reduce their exposure and increase their resilience to air pollution and/or noise.
3. The role that lifestyle factors and occupation may have in influencing sensitivity and vulnerability, linked to socioeconomic status.
4. Evidence of the increased sensitivity and vulnerability of sensitive population groups (i.e. the young and the aging population) to poor air quality and noise.
5. Evidence of how people of lower socioeconomic status are exposed to combined stressors, in particular in urban environments

There are multiple studies showing the relationship between SES and exposure to noise and air pollution, although the relationship is not always clear or straightforward. Adding to this complexity are the multiple measures of SES used in studies (Table 1) and the potential conflation of effects relating to noise, air and other environmental exposures (Orru et al., 2016; Dzhambov et al., 2018).

Generally, reviewed studies show a positive correlation between deprivation and worse environmental conditions, including more industrial pollution, air pollution, and noise, and less access to green space. For example, Šlachtová et al. (2016) provided evidence that population health is affected by both socioeconomic and environmental inequalities and that the uneven distributed of air pollution in Ostrava is related to distribution of socially disadvantaged environment and social exclusion as well. Whilst Wilke (2013) found that people with a low social status are more subjectively and objectively exposed to more noise, in particular road traffic noise.

Empirical support for alternative explanations of environmental inequalities is mixed. While the majority of studies suggest that inequitable distributions of environmental burdens and amenities based on income exist, uncertainty remains about the spatial scale, intention, and causes of the inequalities (Kedron, 2016).

Nevertheless, there are many areas in the city that are affected by multiple stressors, adding to noise and air pollution, the lack of green spaces and a high density of social problems including high unemployment (Klimeczek, 2014); observations highlighted by an integrated city observation system ("Environmental Justice Monitoring") which provides information on the socio-spatial distribution of health relevant environmental pollution and resources. From a public health and urban planning policy perspective, it would therefore be interesting to be able to identify the factors that determine the differential exposure, and to consider the mixed uses and heterogeneous patterns in urban planning in order to try to minimize the differences in exposure.

Finally, in literature, the terms vulnerability and susceptibility are described with considerable variety (see, inter alia, Sacks et al, 2011). This motivated a different committee of the Health Council to exclusively use the term: groups with an increased risk (HCN, 2011). See also Faustini et al, 2010 for definitions. Susceptibility refers to the degree to which individuals and groups may respond to a given exposure. These can be innate and acquired responses. Acquired susceptibility may be due to disease, age or socioeconomic status. It should be noted that socioeconomic status is not a precise identification of a causal factor. Vulnerability is determined by susceptibility, but also by the degree of exposure. In the latter case, vulnerability is therefore also a function of where people live, how and where they spend their time, and their lifestyle. For example, living near busy roads or spending long hours on the road increases vulnerability to air pollution. The vulnerable groups also include people who live at locations with several social risk factors and who have less access to protective measures.

4.1 Factors that help determine the exposure of different socioeconomic groups

- Multiple studies showing the relationship between SES and exposure to noise and air pollution, but relationship is not always clear or straightforward.
- Multiple measures of SES used in studies and potential conflation of effects relating to noise, air and other environmental exposures.
- Some inconclusive and contrary evidence to suggest that those in the lowest socioeconomic groups may not always be the most affected, depending on sources and scales of impact.
- Urbanisation/population density is the key factor determining exposure to noise and air pollution.
- Where people live is a major driver for disparities relating to exposure to noise and air pollution. House price associated with noise, but not air pollution.
- Proximity to roads and green space factor inversely.

An analysis of the evidence relating to exposure of different socioeconomic groups to noise and air pollution reveals that there are multiple, sometimes interrelated, factors at play, and some inconclusive and contrary evidence to suggest that those in the lowest socioeconomic groups may not always be the most affected, depending on sources and scales of impact.

We begin by identifying some of the specific SES factors that are (or are not) associated with exposure to noise and air pollution.

Inequalities in environmental conditions and the lack of distributive justice regarding the location of environmental hazards lead to a greater probability of exposure to environmental health threats. Marginalized and disadvantaged groups – irrespective of the type of disadvantage, which can be education- or income-related as well as gender specific or associated with ethnicity – are most often characterized as having the highest levels of exposure to environmental problems (WHO, 2012).
For example, Oudin et al (2016a) observed associations between dementia incidence and local traffic pollution that remained after adjusting for known risk factors, however, factors related to SES, such as education and smoking, did not influence the observed association, whereas Zubero et al. (2017)

reported that individuals with lower level of education did have higher levels of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/Fs) associated with municipal solid waste plants than participants with university qualifications.

Deguen et al.'s (2017) study examined the combination of individual characteristics identifying profiles of respondents within which the level of air quality satisfaction and the NO_2 concentrations measured are consistent. They identified that age combined with a low level of education and unemployment, or women or health problems as well as the neighbourhood deprivation index influenced the level of air quality satisfaction. Brunt et al. (2017) also found that air pollution concentrations were highest in 'most' deprived areas. When considered separately, deprivation-health associations were stronger than air pollution-health associations, however, when considered simultaneously, air pollution added to deprivation-health associations.

In the Brainard et al. (2002) study in Birmingham, England, it was found that night time noise was significantly elevated in deprived communities and Poortinga, Dunstan and Fone (2008) found in a study carried out in Wales that persons with lower SES were more likely to report noise exposure. According to Shrestha et al. (2016) communities with lower SES are generally exposed to higher levels of air pollutants (PM_{10} and NO_2) more than affluent communities. This finding confirms results of many other studies showing that communities with lower SES are generally exposed to higher levels of air pollutants more than affluent communities. Nevertheless, the degree of inequality in Dortmund is rather small (CI for PM_{10} = –0.009, $p < 0.05$; CI for NO_2 = –0.014, $p < 0.05$) that can be attributed to spatial patterns of these air pollutants similar to street noise exposure (Shrestha et al., 2016).

Where people live is a major driver for disparities relating to exposure to noise and air pollution, with higher exposure found most commonly in urban areas. Air pollution is often highest in specific areas especially where traffic and industry are intense, and therefore different neighbourhoods tend to have different exposure levels affecting the residential population. According to WHO (2013) perceived exposure inequalities are most expressed for income, where persons with a low income (24% reporting major problems with air quality) have an almost 2.5 times higher exposure likelihood than persons with high income (10.2%). This disparity is most likely explained by residential location in disadvantaged and more polluted neighbourhoods.

Aether (2017a) found that populations living in the most deprived areas of London are on average more exposed to poor air quality than those in less deprived areas (46% of the LSOAs within the most deprived 10% of London have concentrations above the NO_2 EU limit value, compared with to 2% above the NO_2 EU limit value in the 10% least deprived areas).

Lejeune et al. (2016) observed that a higher proportion of poor households live in areas with bad air quality (13% in areas of low air quality), whereas only 10% of wealthy people live in these types of municipalities. The converse is also true; where the quality of air is higher, the proportions are reversed, although not substantially. Lejeune et al. (2016) also reported air quality differences between low and high population density settlements. In their study, where population density is low, air quality is low in only 3% of areas, but high in 43%. Conversely, air quality is low in 12% of areas of high population density, and high in 10%. By extrapolation, more densely populated areas would then be more polluted in terms of atmospheric pollution, confirming previous studies.

Milojevic et al. (2017) identified concentrations of the particulate fractions, but not of nitrate $PM_{2.5}$ or ozone, were modestly higher in areas of greater socioeconomic deprivation though pollution relationships were non-linear and varied by urban-rural status. However, such pollution differentials made only a small contribution to socioeconomic gradients in $PM_{2.5}$-attributable life-years lost per 1000 population in both urban and rural areas. Their analyses suggest that such gradients are substantial but mainly because of the gradient in underlying mortality rates across deciles of deprivation (which therefore generate gradients in mortality burdens even with a similar relative risk for $PM_{2.5}$), rather than because of variations in pollution concentrations themselves. In their study the small mortality burden of $PM_{2.5}$ exposure in the most deprived decile in rural areas is due to the small population in such areas. The magnitude of the socioeconomic differentials in $PM_{2.5}$-related life expectancy lost at birth is fairly modest by comparison with the differentials in overall life expectancy between least and most deprived areas.

As well as more typical urban pollutants, exposure to CO concentrations has also been observed. As far as the non-smoking population is concerned, the average exhaled CO level is significantly higher in big city citizens (a high level of air pollution) than in small town and country citizens (a low level of air pollution) (Maga et al., 2017).

Socioeconomic inequality in urban areas can be captured by differential housing values. The EEA Guidelines (EEA, 2010) give an estimation of the house value reduction due to high noise levels analysing the real European estate markets, indicating that on average houses prices lose 0.5% of their value for each dB(A) above 50–55 L_{den}. The value of house depreciation in terms of lost €/dB(A) can be used as a noise score to rank the buildings that are most economically affected by noise. Apartments located in peaceful districts of Paris are worth 1.5% more on average (Glachant and Bureau, 2010). However, depending on the context, the level of noise exposure does not always constitute a significant variable, such in the majority of the 287 French urban centres studied by Cavailhès (2005). Le Boennec and Salladarré (2017) analysed in more detail the relationships between site characteristics, noise and housing values in Nantes Métropole: noise strongly depended on the proximity of the city centre or the number of bus stops in the neighbourhood, reinforcing the depreciation impact noise pollution significantly exerted on housing price. Aircraft noise has also been reported as a negative effect on housing prices, even more than road traffic noise (Kopsch, 2016) (Table 3). For example, a study in Poznan, showed the influence of aircraft noise on different types of housing (Trojanek et al., 2017): the noise depreciation index value was 0.87% in the case of single-family houses, and 0.57% regarding apartments. One of the reasons for the difference in the level of impact of aircraft noise may be the fact that the buyers of apartments may be less sensitive to aircraft noise than the buyers of single-family houses.

Surprisingly, air pollution has no significant impact on the price, although air pollution is still dependant on the proximity to the city centre or to a commercial zone, and on the structure of the individual or public transport network. It may be that the advantages of living in noisier or more polluted areas closer to specific facilities outweigh the assumed negative effects of the consequently higher noise or air pollution levels. If purchasers are prepared to accept higher pollution levels as unavoidable consequences of living closer to facilities, then there might be no reason for the price to be affected. More research on the motivations, perceptions, and preferences of the buyers taking these elements into account should contribute to better understand the impact of environmental variables on the real estate market (Le Boennec and Salladarré, 2017).

Table 3: Summary of recent reviews of literature on aircraft noise depreciation index (Source: Trojanek et al., 2017).

Id	Author(s)	Location	Noise Measure	Threshold dB	NDI	Research
1	Nguy et al. [31]	Beijing, China	–	–	1.05%	130 observations; sales; apartments; 2006–2012
2	Baranzini and Ramirez [32]	Switzerland, Geneva	Ldn	50 dB	1.17%	13,034 observations; rents; apartments; 2003
3	Salvi [33]	Switzerland, Zurich	Leq16	50 dB	0.97%	3737 observations; sales; single-family houses; 1995–2005
4	Dekkers and van der Straaten [34]	Netherlands, Amsterdam	Lden	45 dB	0.77%	66,636 observations; sales; different types of properties; 1999–2003
5	Brandt and Maenning [35]	Germany, Hamburg	Lden	62 dB	1.29%	4832 observations; for sale; apartments; 2002–2008
6	Thanos et al. [36]	Greece, Athens	Lden	55 dB	0.49%	1613 observations; sales; different types of properties; 1995–2001
7	Püschel and Evangelinos [37]	Germany, Düsseldorf	Lden	55 dB	1.04%	1370 observations; for sale; apartments; November 2009
8	Huderek-Glapska and Trojanek [38]	Poland, Warsaw	Laeq (The study is based on the Limited Use Area. The LUA is based on the actual noise indicators (L_{AeqD} and L_{AeqN}) around Warsaw airport and include the aircraft movements over the next five years.)	55 dB	~0.2%	130324 observations; for sale; apartments; 2007–2011
9	Trojanek [39]	Poland, Warsaw	Laeq Laeq (The study is based on the Limited Use Area. The LUA is based on the actual noise indicators (L_{AeqD} and L_{AeqN}) around Warsaw airport and include the aircraft movements over the next five years.)	55 dB	~0.8%	5290 observations; sale; apartments; 2010
10	Winke [40]	Germany, Frankfurt	Lden	55 dB	1.70%	19148 observations; for sale; apartments; 2006–2014
11	Chalermpong [41]	Thailand, Bangkok	NEF	30 dB	2.12%	384 observations; sales; new homes; 2002–2008
12	Boes and Nuesch [42]	Switzerland, Zurich	Leq16	30 dB–50 dB	0.5%	19,721 observations; for sale; rents; 2001–2006
13	Ahlfeldt and Maenning [43]	Germany, Berlin	Lden	45 dB	0.5–0.6%	31,289 observations; sales; different types of houses; 2000–2007
14	Lavandier et al. [44]	France, Paris	Lden	50 dB	Mean value 1.08%	19,891 observations; sales; single-family houses; 2002–2008 (except 2007)
					Mean value 1.51%	23,264 observations; sales; apartments; 2002–2008 (except 2007)

Additionally, different surveys indicate that areas heavily impacted by transport noise often also undergo a spiral of environmental degradation through an attraction pool of environmentally damaging activities, e.g. waste incineration. The package of environmental degradation affecting those areas attracts poor population due to the discount in the value of housing (Pellow et al., 2001). Therefore, noise pollution can stimulate a chain of degradation in quality of life (Muzet et al., 2013). Other authors propose to explore the chicken-and-egg question of what comes first: the polluting activity or the low-income residents (Mitchell, Thomas and Cutter, 1999). A complex mix of social, economic, political, psychological, and environmental factors influence distributional relationships between subpopulations and environmental risks (Kruize et al., 2007). In the same article, the author cited that theories on environmental equity are relatively new and therefore in the pre-paradigm phase. That is probably why no single paradigm had emerged regarding the causes of environmental inequity (Liu, 2001; Pellow et al., 2001). Economic and location theories, theories of power, theories on risk, and theories on neighbourhood change may all contribute to the explanation (Liu, 2001).

Proximity to highly urbanised areas is also often associated with proximity to high traffic volumes. NO_2 concentrations are particularly high in cities near major transport corridors where socio-economically deprived and poor people and ethnic minorities are over-represented (Paavola, 2017). Most research on socioeconomic disparities in environmental exposures has focused on environmental hazards and pollutants, showing, for example, that some disadvantaged urban subpopulations have a higher exposure to ambient air pollution, with motor vehicle traffic as one important source.

Studies within Europe indicate that less affluent population groups are most exposed to environmental risks in their place of residence and that waste facilities are often disproportionately located in areas with more deprived residents (WHO, 2012). Social structure and economic developments in residential areas are closely connected with access to means of transport. Residential areas with a concentration of social problems often have poor access to local public transport. In addition, they are often more troubled by noise and air pollution due to above-average traffic levels (UMID, 2011). People with a low social status in Germany are more exposed to traffic and industry-related air pollutants than people with a high social status (Klimeczek, 2014).

As we have seen, exposures to motor vehicle exhaust and non-exhaust emissions, secondary air pollutants formation, underground, metro and rail, and hence their associated health impacts, are not equally distributed in the population, with lower socio-economic groups being exposed more and bearing the highest burden. As such, transport practices have the potential to increase existing health inequalities (Khreis, May and Nieuwenhuijsen, 2017). However, residents of less affluent areas tend to use active (‘green’) travel modes, although any health benefit may be offset by increased periods of environmental exposure (Jephcote, Chen and Ropkins, 2016).

Air pollution intake relates to the intake by drivers and passengers, among people cycling and walking, and people travelling by underground. Pollutant concentrations are highest on the roads, and decrease as distance from the road increases, so drivers, passengers, and people walking or cycling on or very close to roads are exposed to relatively high concentrations of pollutants. In vehicles, the concentrations are between 1.5 and over 10 times higher than in the ambient air, and the difference between concentrations is greater for CO, benzene and NO_2 compared with $PM_{2.5}$ and PM_{10}. Emissions include emissions from road vehicles driving on the same road (or adjacent road if they cycle on cycle tracks) as well as emissions from vehicles driving on roads further away from where they cycle or walk. In general, the concentration depends on the density and composition (in terms of age and engine/fuel type) of the motorised traffic and the distance to these sources. In addition, ambient factors such as temperature, wind speed and the morphology of the built environment and trees play a role in the dispersion of pollutants and consequently concentrations and exposure. Although cyclists are exposed to lower concentrations than drivers, cyclists inhale more air than car drivers, due to their physical activity. Consequently, they inhale more benzene and CO, and significantly more NO_2 than car drivers. In addition, the exposure of cyclists and pedestrians depends on travel speed. With higher walking and cycling speeds, breath rates will increase, and more pollution is inhaled per unit of time. However, higher speeds also imply a shorter duration of exposure. Laboratory experiments as well as field tests suggest that the latter effect prevails, leading to less exposure when cycling or walking faster. People travelling by underground may be exposed to high concentrations of PM originating from mechanical friction processes, although literature in this area is scarce. The health effects of exposure are diverse and obviously depend on the substance to which one is exposed (van Wee and Ettema, 2016).

It has been found in a study carried out in London that road traffic noise increased slightly while decreasing the SES area-level for all the indicators analysed (income deprivation, employment deprivation, health deprivation and disability, education training and skills deprivation, barriers to housing and services, crime and living environmental deprivation). The relationship is stronger in the case of rail traffic noise and aircraft noise, as observed when comparing exposure from railways and from London City airport with deprivation at area level but also at individual level, mainly focused on the self-reported household income which influences individual lifestyle and behavioural choices. As stated in the article, 10% and 0.3% of individuals in the highest tenth of household income were exposed to noise from railways and City airport, respectively, compared to 15% and 0.9% in the lowest tenth. For Heathrow airport, the trend was opposite, 18% in the highest tenth of household income and 10% in the lowest (Fecht et al., 2017).

As stated by Braubach and Fariburn (2010), housing conditions and environmental quality or residential areas are differentially distributed in the population. Through a literature review limited to European evidence, they highlight that most of the studies identified the less affluent population groups as most exposed to environmental risks in the place of residence, although due to the methodological variety of the available studies and the lack of data for many countries, it was not possible to provide a general assessment of the magnitude of inequity in Europe. In relation to noise, the article identifies that people with lower SES often live nearer to main roads with high traffic noise (in Germany (Bolte and Fromme, 2008; Kohlhuber et al., 2006; Hoffmann et al., 2003), Switzerland (Braun-Fahrländer et al., 2004) and The Netherlands (Kruize and Bouwman, 2004)). In addition, Swiss data show that 65% of the households with lowest SES live in areas with industrial activities where background noise levels are around 7 dB(A) higher than in residential areas (Braun-Fahrländer et al., 2004).

In a more recent study from the Dutch Rijnmond region (Kruize et al., 2007), it was found exposure levels higher than the (legal) standards, associated with lower income only for rail traffic noise, but an exception was found for aircraft noise for which high income was associated with increased exposure (Kruize et al., 2007). Additionally, the same study demonstrated the relationship between higher-income groups and the availability of public green space. (Kruize et al., 2007).

Finally, the results of a study on adult health done in Germany, and conducted by the Robert Koch Institute (RKI) from 2008 to 2011, also show a stronger road traffic burden on people with low SES. According to this study, 28.3% of low-social-class respondents reported living on a busy or on an extremely busy street, but only 14.8% of the upper status group reported the same (Laußmann et al., 2013). However, this relationship is the outcome of interaction of multiple factors. Therefore this connection is not always present as found by Lakes and Brückner in a study undertaken in Berlin, where it has not been possible to establish a statistically significant relationship between noisy residential areas and the social structure at the planning area level, where a heterogeneous pattern of socio-spatial distribution of noise pollution levels is observed (Lakes and Brückner, 2011). In the same line, in Vienna, a neighbourhood socioeconomic position index (NSPI) and a road traffic noise index (RTNI) showed a weak correlation (Siedl, 2016).

Accessibility to green urban areas may be a factor that decreases the differential exposure according to SES. As evidenced in the different studies analysed, people with lower incomes and lower education levels tend to have poorer access to environmental resources, and among these, access to green and open spaces. This situation occurs in: Berlin (highlighted in the results of the project "Environmental Justice in the Land of Berlin" (Kleinschmit et al., 2011)); in Munich (in a study carried on from 2004 to 2007 on health monitoring and living environment, summarized by Thiele and Bolte, (2011); in Frankfurt (where a survey undertaken by Schade, (2014) demonstrates that families with low social status often report a longer walk to the nearest green space than socially better off families); in the Rijnmond region in the Netherlands where lower levels of public green areas have been found for low-income neighbourhoods (five times less than for highest income groups) (Kruize et al., 2007); and also for low-income households in Bavaria in Germany (Bolte and Fromme, 2008).

Padilla et al. (2016b) also found that high deprived census blocks were more exposed to air pollution according to the definition of the proximity to the high-traffic roads within a buffer of 150 m and less exposed to "positive" environmental exposure, by definition the proportion of green space or relation to the recommendations the meter square of green space per habitant by census blocks. This result was similar with previous studies in France (Lille, Marseille) which reported that the most deprived neighbourhood are located in census blocks with the highest level of NO_2 concentrations, in Europe, in Canada or in United States. Moreover, regarding residential surrounding greenness and proximity to green spaces, previous studies have reported that individual SES could modify the health benefits of green spaces. In this context, neighbourhood SES could also have a potential modifying effect on the association between green spaces and health (Padilla et al., 2016b).

The direction and degree of social inequalities in complaints about lack of access to recreational or green areas depends on the local or regional situation in a given country or region, and on the socioeconomic indicator analysed. The expectation that disadvantaged groups might be more affected by a lack of access to recreational or green areas is mostly met in the EU15 region[29], while NMS12[30] and Euro 4 sub-region[31] countries show more variation (WHO, 2012). Wüstemann, Kalisch and Kolbe (2017) investigated access to urban green on household and individual level and identified strong disparities in green space provision in German major cities.

In a cross-sectional survey of 399 participants (15–25 years of age) in the city of Plovdiv, Bulgaria, Dzhambov et al. (2018) compared single and parallel mediation models, which estimate the independent contributions of different paths, to several models that posit serial mediation components in the pathway from greenspace to mental health. They tested perceived air pollution as a mediator between objectively measured greenspace and health and found greater tree cover density in closest proximity to people's homes associated with lower air pollution perception and in turn better mental health in the single mediation model. Perceived air pollution was also associated with some self-reported greenspace measures (visible greenery from home, walking time to greenspace, and greenspace quality) and acted as a single mediator for them. This is concordant with beliefs that urban vegetation has the potential to reduce various air contaminants and to improve air quality, which may lead to lower psychological stress and better self-rated health. When adjusted for the other mediators,

[29] 15 Member States belonging to the EU before May 2004 (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom)
[30] 12 Member States joining the EU after May 2004 (Bulgaria, Czech Republic, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia)
[31] All countries in the south-east of the WHO European Region including the Balkans, Turkey and Israel

perceived air pollution no longer mediated the effect of greenspace in the parallel models (Dzhambov et al., 2018). In some subgroups people reporting difficult or no access to recreational/green areas experienced stronger adverse effects of perceived residential pollution. There was a statistically significant effect modification across different exposure-access scenarios, but it was clearer for air quality than it was for noise. The most pronounced effects were among people who did not use recreational/green areas at all. In summary, promoting "exposure" to urban greenspace might be considered as an eco-social approach to alleviate the adverse effects of environmental pollution (Dimitrova and Dzhambov, 2017).

Spatial variability in exposure to traffic pollutants, associated with SES has also been observed. Padilla et al. (2016a) identified city-specific patterns of spatial inequalities in infant and neonatal mortality over time, where the influence of deprivation index and NO_2 exposure in the geographic variation of these outcomes differs depending on the area and time period. Tonne et al. (2016) investigated all-cause mortality and hospital readmission for myocardial infarction (MI) among MI survivors, but found that there was no evidence that primary traffic pollutants were more strongly associated with prognosis compared to pollutants reflecting regional or urban background. Stroh et al. (2005) report that SES and the levels of NO_2 in the area of residence are associated in some cities, but that the associations vary considerably between cities within the same county (Scania). Even for cities of similar sizes and population bases the associations observed are different. Studying the cities together or separately yields contradictory results, especially when education is used as a socio-economic indicator. Unequal distribution to air pollution exposure according to SES groups is complex in European cities and no general pattern exists across cities, but rather inequalities need to be specifically assessed in each city. It is also important to take into account both individual- and neighbourhood-SES in order to fully describe and understand the complexity of current patterns of social inequalities relating to air pollution (Temam et al, 2017).

Affluence is not always an accurate indicator of exposure to air pollution, however. Some elements of air pollution can be higher in some wealthy zones such as Central London due to traffic levels (Saunders, Middleton and Rudge, 2017). Population profiling of NO_2 hotspots showed that, unlike other parts of the UK, more affluent people in Sandwell are likely to live in areas of poor air quality. Over 27% of Sandwell families were found to live close to busy roads but, given the wide distribution of such roads in Sandwell, there was little evidence that any specific groups were disproportionately represented (Saunders, Middleton and Rudge, 2017).

Exposure to industrial pollutants are also subject to complex socioeconomic disparities. In a study of Flemish adolescents, Morrens et al (2012) found that chlorinated compounds (PCBs and pesticides HCB and DDE) are positively associated with SES (higher exposures for higher SES), while heavy metals (lead and cadmium) are negatively associated (higher exposures for lower SES). For metabolites of organic compounds (benzene and PAHs), however, no association with SES was found. In a study by Gianicolo, Mangia and Cervino, (2016), two air pollution exposure patterns were identified in relation to proximity to an industrial site characterised by high mortality levels: a proximal one characterised by exposure to PM_{10} and a distal one characterised by exposure to SO_2. The former affects residents close to the industrial site and is largely associated with the extensive diffuse and fugitive emissions derived from the industrial site; the latter impacts residents at a distance downwind from the industrial site, and is likely associated with emission of pollutants from taller stacks (Gianicolo, Mangia and Cervino, 2016).

Other factors that affect exposure that may have socioeconomic links relate to adherence to health advice and air quality warnings. Frequent suboptimal levels of adherence to health advice accompanying air quality alerts and indices was found in a review study by D'Antoni et al. (2017). Although demographic factors did not consistently predict adherence, several psychosocial facilitators of adherence were identified. These include knowledge on where to check air quality indices, beliefs that subjectively experienced symptoms were due to air pollution, perceived severity of air pollution, and receiving advice from health care professionals. Barriers to adherence included: lack of understanding of the indices, being exposed to health messages that reduced both concern about air pollution and perceived susceptibility, as well as perceived lack of self-efficacy/locus of control, reliance on sensory cues and lack of time (D'Antoni et al., 2017).

Future changes in atmospheric chemistry, due to climate change and management of precursors, may also serve to increase exposure to air pollutants. For example, if PM concentrations have similar distribution patterns to NO2 then their increase in changing climate would increase the exposure of the same people to the adverse health outcomes of PM. The situation with O3 is more complex as high urban NO and NO2 concentrations inhibit the formation of O_3. However, high O_3 concentrations can prevail in cities in future if public policies do succeed in bringing down urban nitrogen oxide emissions (Paavola, 2017).

4.2 Reflections on how people on higher incomes can reduce their exposure and increase their resilience to air pollution and/or noise

- Little evidence relating to the ability of more affluent individuals or households to be able to avoid air or noise pollution.
- Primarily relates to residential location as a demonstration of their ability to implement ‘willingness to pay’ behaviour.
- With regard to noise, an increase of the willingness to pay with an increase in annoyance has been observed, but no dependence on source.
- In the UK, annual mean NO2 concentrations have fallen more in more affluent areas, but PM10 concentrations have increased more in poorer areas.

There is little evidence relating to the ability of more affluent individuals or households to be able to avoid air or noise pollution. Where it exists, this primarily relates to residential location as a demonstration of their ability to implement ‘willingness to pay’ behaviour. As seen in the previous section, where exposure is inversely proportionate to SES, this may be as a result of the location of low-cost housing in areas subject to high levels of noise / air pollution. This may be compounded by a higher likelihood for more polluting industries to be located in these areas and for them to be more heavily trafficked. Furthermore, the social status of these ‘deprived’ areas may be reinforced by more affluent householders exercising their ability to choose not to live in those locations, although it is unclear whether this is knowingly to avoid exposure. Conversely, areas with low exposure levels may also be associated with greater distance from busy roads and more greenspace, attracting wealthier residents and excluding those in lower socioeconomic groups.

This phenomenon is in some way evidenced by Jephcote, Chen and Ropkins (2016) who identified that Leicester's (UK) most affluent communities were located along the city's periphery, where traffic pollution was lowest, in contrast to poorer households that resided in more central, more highly polluted areas (Jephcote, Chen and Ropkins, 2016). This study is revisited in section **Error! Reference source not found.** in a discussion of disparities in SES relating to generation of pollution.

Environmental policy appears to be reinforcing this injustice, at least in the UK. Mitchell, Norman and Mullin (2015) identified that annual average NO_2 concentrations have fallen markedly, but the rate of improvement has been slower for the more deprived; effectively all of the most well off are lifted out of exceedance, compared to 70% of the most deprived. Conversely annual average PM_{10} concentrations have risen, and done so more quickly for the poor (Mitchell, Norman and Mullin, 2015).

On the other hand, Le Boennec and Salladarré (2017) tested the assumption of the way environmental variables could be simultaneously affected by specific attributes of the houses exchanged in Nantes and its metropolitan area, and could affect housing price, and showed that air pollution had no significant impact on the price, whereas noise pollution does have an impact (Le Boennec and Salladarré, 2017).

With regard to noise specifically, an increase of the willingness to pay with an increase in annoyance has been observed, with no differences observed depending on the noise source. So, the more a person is annoyed the more he or she is willing to pay for an improvement of the situation and the more they have the opinion that a quiet living environment is luxury. And, although a quiet living environment is a right of every person, it is affordable only for rich people (Giering et al., 2017). In the NORAH study (http://www.laermstudie.de/en/) it was seen that many people already found air traffic noise at relatively low sound levels more annoying than considerably louder rail and road traffic noise, indicating the influence of the subjective nature of noise exposure.

4.3 The role that lifestyle factors and occupation may have in influencing sensitivity and vulnerability, linked to socioeconomic status

- Confounding factors relating to lifestyle are inherent in studies relating to noise and air pollution.
- Limited evidence specifically on role of lifestyle or occupation.
- While lifestyle may be linked to SES, lifestyle factors (e.g. smoking) may be independently related to exposure and may have an additive effect in terms of health impact.
- Occupational risk factors generally captured by health and safety thresholds.
- Higher blood pressure was observed in traffic-police cf. other outdoor workers; cardiovascular disease mortality associated with women in routine jobs, and anxieties related to job insecurity and traffic-related exposures observed.

Confounding factors relating to lifestyle are inherent in studies relating to noise and air pollution exposure in which relatively short-term (e.g. daily) temporal variations in exposure and long-term (life-course) exposure all contribute to health impacts. The multitude of different (indoor and outdoor) exposures and additional effects relating to lifestyle (e.g. smoking, diet) experienced within those timeframes are difficult to unpick in epidemiological studies, however, evidence presented here demonstrates some of this complexity. Studies relating to occupational risk factors are more limited, largely as by its nature this kind of exposure is generally captured by health and safety thresholds as opposed to ambient concentrations. Furthermore, we have not included studies relating to indoor air and indoor noise, thereby excluding the vast majority of workplace exposures. Instead we have included studies which refer to ambient exposure relating to outdoor occupations only.

Long-term air pollution concentrations estimated at the home address in the Netherlands were associated with individual risk factors related to lifestyle. For most lifestyle-related risk factors, unhealthy lifestyle was associated with higher air pollution exposure, however, being overweight was associated with lower air pollution concentrations. The differences in concentrations between "healthy" and "unhealthy" lifestyles, although often statistically significant, were generally small (<5% of the pollutant standard deviations) and the observed associations differed per pollutant, probably due to regional and intra-urban spatial variability of pollutant concentrations. After adjusting for variables, i.e., age, sex, education, occupation, income, marital status, ethnicity and neighbourhood SES, the associations between lifestyle factors and air pollution were often reduced but still present. This suggests that either the association between air pollution and lifestyle is not exclusively due to differences in SES or that the indicators available do not fully characterize SES (Strak et al., 2017).

In a study by Bagordo et al. (2017) information about exposure factors linked to the home context and lifestyle of 1,164 children aged 6–8 years attending primary schools in five Italian cities were analysed against varying geographical, environmental, demographic and socio-economic characteristics. Frequency of some factors appeared different in terms of the survey season (physical activity in the open air, the ways of cooking certain foods) and among the various cities (parents' level of education and rate of employment, sport, traffic near the home, type of heating, exposure to passive smoking, ways of cooking certain foods). The socio-economic level seems to affect the lifestyles of children enrolled in the study including those that could cause health effects. Many factors are linked to the geographical area and may depend on environmental, cultural and social aspects of the city of residence (Bagordo et al., 2017).

Morrens et al. (2012) identified that in relating SES of Flemish adolescents to exposure to industrial emissions, socially constructed factors, such as dietary and lifestyle habits, play an important role in these relations

Health status, resulting from certain behaviours (such as smoking) has an impact on the health effects resulting from exposure to traffic pollutants (van Wee and Ettema, 2016). Maga et al. (2017) found that permanent exposure to an increased concentration of air pollution in densely populated areas as well as cigarette smoking have a clear impact on the average level of exhaled CO and, moreover, both effects are additive. Kamusheva et al. (2017) demonstrated a significant clinical and socio-economic burden of COPD in Bulgaria, concluding that besides high rates of smoking, occupational risk factors and air pollution may explain these findings.

As mentioned, evidence of occupational exposure to ambient concentrations of air pollutants were limited, however, in a study of outdoor workers, systolic and diastolic blood pressure was significantly influenced by the kind of task: outdoor workers, daily exposed to urban air pollutants and noise, develop high blood pressure levels. Among outdoor workers, traffic policemen were found to have levels of blood pressure higher than environment technicians because of their exposure to higher concentration of fine and ultrafine particles (inhalable and respirable particles), NO_2, metals and solvents. Environment technicians spend part of their work shift in parks and green areas and are therefore less affected by the urban air pollution produced by vehicular traffic, but are exposed to the volatile components of the gasoline used for their work equipment and machines. For environment technicians, the noise could have instead great influence on systolic and diastolic blood pressure, because of the daily exposure to work equipment, such as chainsaws, mowers, trimmers and lawnmowers. Increase of blood pressure in outdoor workers was thus assumed to be due to a combined effect of multiple particles present in air pollution. This global toxic action would be greater than the sum of the effects of each substance individually considered and that extra occupational factors might also influence and interfere (Tomei et al., 2017).

In one particular study, women in routine jobs were found to experience five times higher cardiovascular disease mortality than women in managerial and professional jobs. These differences in cardiovascular mortality risk and sensitivity to O_3 and PM pollution emerge from differences in the levels of deprivation, lifestyles, health literacy, access to health services, and environmental exposure. Social deprivation and ethnicity can also constrain adaptive capacity by limiting ability to relocate and to take other measures to avoid exposure or to reduce sensitivity (Paavola, 2017).

Employment is also relevant when determining vulnerability, not only with regard to direct exposure, but also in relation to the stresses of job insecurity. Longitudinal studies have consistently shown that high job insecurity predicts poor health outcomes and with labour markets growing more and more unpredictable, perceptions of job insecurity have increased across European Union Member States and beyond (De Witte et al., 2016). In line with earlier population-based studies on either job insecurity or annoyance due to noise pollution and/or air pollution, Riedel et al (2017a) observed positive associations with self-rated poor health. What is more, these exposures, if examined based on the same database, show both statistically independent and joint associations with incident self-rated poor health. In Germany it was found that after 2-year follow-up in 2011, 571 (8.7%) participants rated their health as poor (Riedel et al., 2017b). The risk of reporting incident poor health was increased by roughly 40% in employees reporting high versus low perceived job insecurity and annoyance due to noise and air pollution. This risk increased when both exposures were present at higher levels. Work-related and environmental exposures may accumulate and have a joint health impact. Elaboration on the link between occupational and residential exposures is warranted in the light of their concurrence and their implications for health inequities.

In view of these current developments, it is plausible to assume that job insecurity and traffic-related exposures are likely to concur in residential and occupational contexts. This may hold true particularly for socially disadvantaged subpopulations. This notion is in line with social epidemiological models on health determinants and inequities, which highlight the accumulation of exposures across contexts (Riedel et al., 2017b).

4.4 Evidence of the increased sensitivity and vulnerability of sensitive population groups (i.e. the young and the aging population) to poor air quality and noise

- High exposure + low SES + increased susceptibility of SES = "triple jeopardy" effect (Jerrett et al., 2001).
- + vulnerable groups = "quadruple jeopardy" effect.
- Children, including prenatal, the elderly and those with existing health conditions may be more represented in lower SES groups and in areas with higher exposure to noise/air pollution and are more susceptible to the resulting health impacts.
- Evidence is not unanimous.

Increased exposure to air and noise pollution in low socioeconomic groups can be compounded by the susceptibility of these groups to the effects of exposure (WHO, 2012), a combination of factors has been described as the "triple jeopardy" effect (Jerrett et al., 2001). Within these highly exposed, low socioeconomic groups there may also be individuals with increased sensitivity to exposure. For instance the elderly, infants or pregnant women are more sensitive to certain pollutants (van Wee and Ettema, 2016). This effectively adds another dimension to vulnerability which could then be considered a "quadruple jeopardy" effect. We consider here studies that explore these differences in sensitivities within socioeconomic groups and their vulnerability to air and noise pollution.

Most noise studies in this context focuses on the impact on annoyance, reading impairment and mental health. For example, results in Norway indicate that road traffic noise has a negative impact on children's attention and no mediation by sleep duration (Weyde et al., 2017). Moreover, considering children's annoyance non-acoustic factors are also relevant. In France it has been observed that noise indicators in front of the child's bedroom, family residential satisfaction and socioeconomic characteristics of the individuals and their neighbourhood remained associated with child annoyance (Grelat et al., 2016). These findings illustrate the complex relationships between our environment, how we may perceive it, social factors and health.

Data from the school-starter study Saxony-Anhalt, which were surveyed from 1991 to 2009, indicate the possible effects of housing conditions on health. For example, the occurrence of diseases such as bronchitis, pneumonia and sinusitis in children has been shown to be associated with increased car traffic in deprived areas. The further the kindergarten was from a busy road, the lower the likelihood that children would contract one of these diseases. Furthermore, there were correlations with the social situation of the children: they came from families with a lower social status, they lived closer to busy roads and proved to be more susceptible to common cold (Gottschalk et al., 2011).

In a study of London schools, over 85% of the schools which are most affected by poor air quality have pupils from catchments which are more deprived than the London average, however, in terms of the contribution of travel to school to local air pollution, the schools most affected by air pollution had lower levels of travel to school by car compared with the London average (Aether, 2017b). In a Greenpeace study (2017) the locations of schools, colleges and registered childcare providers were mapped against latest available government estimates for nitrogen dioxide levels on the major roads network and found at least 2,092 education or childcare providers , including 1,013 nurseries, across

England and Wales within 150m of a road breaching the legal limit for NO_2 pollution. This built on earlier findings by Aether (2017a) which had identified 802 (~25%) schools within London within 150 m of roads exceeding the EU annual mean limit value for NO_2.

A study analysing the pathways linking road traffic noise to general mental health in Bulgarian youth find that higher noise exposure was associated with worse mental health only indirectly (Dzhambov et al., 2017). More specifically, results indicated independent indirect paths through noise annoyance, social cohesion, and physical activity. In addition, it was observed that more noise annoyance was associated with less social cohesion, and in turn with worse mental health; noise annoyance was also associated with lower neighbourhood restorative quality, thereby with less social cohesion and physical activity, and in turn with worse mental health. However, causality could not be established.

At a national level for England and Wales, Barnes and Chatterton (2017) confirmed and strengthened the findings of Mitchell and Dorling (2003), which identified a clear inverse relationship between exposure to annual mean concentrations of NO_2 and the percentage of households in poverty, and, moreover, highlighted that these relationships change over the life-course, with households with young children (<5 years) at greatest risk from exposure. Brunt et al. (2017) found that interactions between air pollution and deprivation modified and strengthened associations with all-cause and respiratory disease mortality, especially in 'most' deprived areas where most-vulnerable people lived and where health needs were greatest. Whilst higher values of pollutants exist in urban core areas where communities with a higher social vulnerability tend to live, however it also follows a linear pattern along major roads and highways in the urban fringe where communities with lower vulnerability live (Shrestha et al., 2016).

Other studies also provide mixed evidence on the vulnerability of sensitive groups. According to Aether (2017a) under 19s and over 65s are not disproportionately exposed to high levels of air pollution concentrations in London. Moreno-Jiménez et al. (2016) also found that zones with higher shares of children aged 0–4 appear relatively privileged in the Spanish cities of Madrid and Barcelona compared to the whole population's NO_2 burden. This is derived from lower NO_2 pollution in peripheral areas where young population is more abundant. In Madrid, elderly people are significantly over-exposed to this pollutant, because they are over-represented in inner city neighbourhoods, according to a well-known demographic pattern. In Barcelona, the results point to the same trend, but the relation is not statistically significant. Concerning immigrants, the results presented show a prevalent trend. In Barcelona all groups suffer inequity regarding the NO_2 pollutant, whereas in Madrid the situation is more diverse: in relative terms Latin American and Asian people are penalised, while Africans and Europeans benefit (Moreno-Jiménez et al., 2016).

Despite the variable evidence on the exposure of sensitive groups to air pollution, there is consistent evidence in Europe that socioeconomic differences in exposure to ambient air pollution, noise, second-hand smoke and lack of access to green spaces exist especially among children (WHO, 2012) putting them at a greater risk of the associated health consequences (Ahern et al., 2017).

These impacts may be experienced from before birth. Vriens et al. (2017) identified independent effects of cord blood As, Tl and ß-HCH on placental mitochondrial DNA content, pointing towards the important role of mitochondria as a target of multiple pollutants at low foetal concentrations. Merklinger-Gruchala, Jasienska and Kapiszewska's (2017) research conducted on a very large population of infants suggests that the odds ratio for low birth weight (LBW) may vary with respect to parity and that multiparous mothers are more susceptible to unfavourable prenatal conditions such as exposure to carbon monoxide. These findings provide additional evidence for the relationship between air pollution and LBW by identifying a vulnerable subgroup of mothers. Morelli et al. (2016) also found the impact of $PM_{2.5}$ on mortality, lung cancer and term low birth weight tended to be highest in areas with a moderate to high social deprivation index, and lowest in areas with lowest social deprivation.

In a study by Cohen et al. (2017), age-standardised death and Disability-Adjusted Life Year (DALY) rates due to exposure to $PM_{2.5}$ were higher in males than females, as a result of higher all-cause mortality rates in males (1018.6 per 100,000 males vs 703.4 per 100,000 females). They were also higher in elderly people (age >70 years) than in children (age <5 years), mainly because of age-related differences in mortality from non-communicable diseases (41.4 per 100,000 children aged 1–5 years vs 2914.4 per 100,000 adults aged 70–74 years). Ambient $PM_{2.5}$ contributed to 202,000 (95% UI 152,700–254,600) deaths and 17.4 million (13.1 million to 21.9 million) DALYs from lower respiratory infections (LRI) in children younger than 5 years. In World Bank high-income countries, exposure to ambient $PM_{2.5}$ contributed to 4.3% of total deaths in 2015 versus 9.0% in upper-middle-income, 8.7% in lower-middle-income, and 4.9% in low-income countries. These differences in attributable mortality mostly reflect the fraction of total deaths from cardiovascular disease among countries (Cohen et al., 2017).

Padilla et al. (2016a) also looked at city-specific patterns of spatial inequalities in infant and neonatal mortality over time but found that the influence of deprivation index and NO_2 exposure in the geographic variation of these outcomes differs depending on the area and time period.

García-Pérez et al. (2016c) provide some epidemiological evidence that living in the proximity of industrial areas and agricultural crops may be a risk factor for childhood renal cancer. Specifically, children living near plants involved in the metal industry, glass and mineral fibres, ceramic, organic chemical industry, hazardous waste, urban waste-water treatment plants, and food and beverage sector showed an increased risk. In addition, analysis by group of substances showed a statistically significant excess risk of childhood renal tumours in the proximity of installations releasing carcinogens, pesticides, persistent organic pollutants, solvents, non-halogenated phenolic chemicals, polycyclic aromatic chemicals, metals, and volatile organic compounds.

According to Morrens et al. (2012), depending on the type of pollutant, adolescents with a lower SES either have higher or lower internal concentrations. The association between individual SES and the internal body concentration of exposure to environmental pollutants in Flemish adolescents is more complex than can be assumed on the basis of the environmental justice hypothesis.

As well as physical health impacts, as with noise pollution, exposure to air pollution has been associated with mental health impacts too. For example, Alvarez-Pedrerol et al. (2017) found that short periods of exposure to elevated concentrations during commuting between home and school is associated with adverse impacts on cognitive development in schoolchildren.

In a longitudinal study of Swedish children and adolescents, neighbourhood air pollution concentration was associated with dispensed medications for certain psychiatric disorders, after adjusting for individual-level and group-level characteristics. The association was present in three out of four counties within Sweden. This is one of a small number of studies to consider the association between air pollution and mental health, and the first to do so in children. Furthermore, associations between longer-term exposure to air pollution and anxiety and stress were recently reported in two aging cohorts (Oudin et al., 2016b).

Casas et al. (2017) show that ambient levels of PM_{10} and O_3 may trigger suicide mortality in Belgium, a country with the highest air pollution levels and suicide rate in Western Europe. Age significantly modified the trigger effect of PM_{10} on suicide mortality regardless of the season, with significant trigger effects among extreme age groups (children and elderly). The study does not claim that air pollution causes people to commit suicide, however, the findings suggest that when people commit suicide, they are more likely to do so when air pollution is high (Casas et al., 2017).

The vulnerability of older people to health impacts from air pollution may be exacerbated by a number of interrelated factors. Older people are more sensitive to heat because of their weaker ability to thermo-regulate and because they have other medical conditions. They are also more likely to have prescribed medication, some of which is associated with increased risk for heat related death. Their adaptive capacity may be limited by isolation or lack of information, mobility or autonomy. Lack of autonomy, and lack of care staff awareness and preparedness, may for example prevent or obstruct behavioural and other adaptations in residential or nursing homes. Alignment of the above factors accentuates vulnerability. The pollution of air by NO_2, O_3 and PM is associated with increased all-cause and cardiovascular mortality and morbidity, and exposure to elevated concentrations of ozone over shorter periods of time is associated with increased respiratory mortality and morbidity (Paavola, 2017).

Long-term NO_2 exposure is likely to exacerbate short-term effects of particulate matter in very old people and in those suffering from arrhythmias and COPD, possibly by increasing the oxidative stress already present in the elderly and in these patients (Faustini et al., 2016).

When socio-economic deprivation and air pollution (assessed on the basis of NO_2 measurements) are taken into account, lung cancer mortality among persons aged over 64 years is similar in the city of Madrid and Greater Madrid area (and higher in both than in the rural area), though among persons aged under 65 years, lung cancer mortality is statistically significantly higher in the city of Madrid (Domínguez-Berjón, Gandarillas and Soto, 2016).

Analysis of air pollution and hospital admissions for cardiovascular and respiratory diseases in the whole population of London found little evidence of positive associations, however, some non-linear associations were observed, especially in the elderly. For some outcomes there was evidence of effect modification by area-level socioeconomic deprivation, with an increasing trend across deprivation quintiles and small but significant positive associations in the highest deprivation group (Halonen et al., 2016).

Cournane et al. (2017a) examined high-risk groups (older persons, those of low SES status, or with more debilitating disease) to establish whether they had a worse outcome if admitted to hospital on days with higher levels of air pollution, by quintile. It was found that for the older admission cohort (≥70 years), as admission day pollution increased (NOx quintiles) the 30-day mortality was higher in the elderly. Furthermore, those in the lower SES groups and those patients with more disabling disease were at increased risk with increased quintiles of pollution on the day of their admission. Thus, it has been shown that there is an adverse effect on at risk groups where there is an increase in levels of pollutants on the day of admission to the hospital (Cournane et al., 2017a).

Those with pre-existing health problems may also be more vulnerable to the effects of exposure to pollution. Maheswaran et al. (2016) examined whether pre-existing risk factors for stroke, which included sociodemographic factors, lifestyle-related risk factors and pre-existing medical conditions, increased susceptibility to air pollution related ischemic stroke and found little to suggest that these pre-existing risk factors increased susceptibility to the adverse effects of air pollution on ischemic stroke risk. However, Tonne et al. (2016) found that long-term exposure to air pollution is associated with all-cause mortality and hospital readmission for myocardial infarction (MI) among MI survivors, whereas Cournane et al. (2017b) demonstrated that SES influenced both the admission rate incidence and 30-day in-hospital mortality for respiratory emergency medical admissions; however, prevailing environmental conditions (air pollution and temperature) at time of admission appeared relevant to the in-hospital mortality but did not increase the admission incidence rates.

If people in low SES groups are more likely to be exposed to environmental hazards, then their health will be even more seriously compromised. There is also some evidence that suggest that deprivation might exacerbate the effects of environmental exposure, by making those exposed more susceptible to environmental factors, perhaps because of their impaired prior health status or because of their poorer access to health care (Marmot and Wilkinson, 2006; O'Neill et al., 2003). The combined effects of deprivation and environmental exposure are likely to be more complex than additive. Spatial correlations between the different environmental hazards also imply that exposures will rarely occur singly, and that more deprived populations are likely to be subject to complex exposure mixtures, though the health effects of such exposure mixtures are not well understood (Briggs et al., 2008).

4.5 Evidence of how people of lower socioeconomic status are exposed to combined stressors, in particular in urban environments

- Living in urban areas brings a complexity of interrelated issues, beyond increased exposure to air and noise pollution, e.g. UHI effect, crowding, substandard housing and lack of access to greenspace.
- People with lower SES are also subject to increased vulnerabilities and sensitivities, e.g. poor diet, suboptimal health care, stress, violence.
- The combination of low SES and exposure to these combined stressors is therefore of additional concern.
- Spatial correlations between different environmental hazards also imply that exposures rarely occur alone. Therefore more deprived populations are likely to be subject to complex exposure mixtures.

As the earlier sections have demonstrated, living in urban areas brings a complexity of interrelated issues to bear, beyond increased air and noise pollution. People with lower SES are also subject to increased vulnerabilities and sensitivity as described in section **Error! Reference source not found.**. The combination of low SES and exposure to these combined stressors is therefore of additional concern.

OECD's Health at a Glance: Europe 2016, report highlights a number of socioeconomic determinants of health including: smoking, alcohol consumption, obesity, fruit and vegetable consumption, physical activity, illicit drug use and air pollution (OECD, 2016). Socioeconomic differences in exposure to ambient air pollution, noise, second-hand smoke and lack of access to green spaces have repeatedly been shown to exist especially among children in Europe (WHO, 2012).

Cumulative risk factors including physical environment – noise, crowding, and substandard housing quality– have been identified as strong mediators between SES and neurobiological outcomes across the lifespan (Kim et al., 2018). Therefore, it is of paramount importance to consider the timescale of the exposure to risk factors. However, a study from Germany examining the association and cumulative impact from aircraft, road traffic and railway noise against heart failure or hypertensive heart disease (HHD) in a large case-control study, did not find a direct relationship between the SES of the participants and the risk estimates for heart failure/hypertensive heart disease (Seidler et al., 2016). Nevertheless, people with a low social status in Germany are more exposed to traffic and industry-related air pollutants than people with a high social status. They also feel more often harassed by external environmental factors (Klimeczek, 2014).

Social structure and economic developments in residential areas are closely connected with access to means of transport. At the same time, these areas have to cope with a concentration of difficult social situations. The resident population is therefore disadvantaged in two respects: although the level of car ownership is low and access to mobility for low-income households often limited, they are exposed to high air and noise pollution and an increased accident hazard while the quality of their living environment is poor (UMID, 2011). Transport practices thus have the potential to increase existing health inequalities, contributing further to the ill health of the most deprived groups, who exhibit a variety of other factors that makes them more vulnerable to environmental exposures (e.g. poor diet, suboptimal health care, stress, violence etc.) (Khreis, May and Nieuwenhuijsen, 2017). Importantly, the toxic health effects of vehicle-related pollution are greater in those socioeconomically deprived, living closer to busy roads, in poor housing, with inadequate diet, accompanying tobacco smoking and in the presence of family stress (Holgate, 2017).

Living in urban areas can also exacerbate the health impacts of noise and air pollution through exposure to heat. People living in urban settlements are more exposed than those living in rural areas due to the urban heat island (UHI) effect. Densely built neighbourhoods with limited open space and green areas increase people's exposure to heat, but the geometry of the buildings and how they are built also influence exposure. Top floor flats experience greater thermal stress than ground floor flats. Ventilation has substantial influence on heat exposure, which, paradoxically, may be constrained by considerations for noise and air pollution, as well as physical building design. Many of these factors leading to greater exposure come together in deprived urban neighbourhoods. Social deprivation and age pre-dispose people for cardiovascular illnesses, which in turn compounds the effects of elevated O_3 and PM concentrations on their health. In 2008, the most deprived quintile in the UK experienced 50% higher cardiovascular disease mortality than the least deprived quintile (Paavola, 2017).
Associations between dispensed asthma medications and levels of air pollution at the home address, were observed to be stronger in children to parents with high education, but stressors linked to socio-economy or mental health problems were not found to increase susceptibility to the effects of air pollution on the development of asthma (Oudin et al., 2017).

In summary, there are many socioeconomic determinants of health, many of which may be experience cumulatively in urban environments and over the life course. The combined health impacts of these cumulative stressors is not always clear, however, those in low SES have been found to be more susceptible in some cases.

5 Impacts of socioeconomic status on generation of air pollution

- No evidence was found on the relationship between SES and generation of noise pollution.
- For air pollution, evidence to suggest more affluent households are net-polluters, but confounding evidence to indicate that the picture is less clear-cut.
- In England and Wales, lowest proportion of households in poverty have on average higher emission factors per household than areas in the highest percentile. Further analysis also reveals that those areas in the lowest percentile, i.e. high SES, own the most vehicles, including the most diesel vehicles, have on average older vehicles and drive the furthest, therefore generating the greatest total emissions and contributing disproportionately to traffic-related pollution.
- Across Europe, however, lower SES groups are more likely to drive second-hand cars.
- Low SES groups are also more likely to use sustainable modes.
- Further evidence required on the role of SES in generation of air pollution from domestic solid fuel-burning.

The premise of this section was to identify whether there was evidence that higher socioeconomic groups were contributing more to the generation of pollution to complement discussions on environmental injustice relating to exposure. Whilst there is evidence to suggest that more affluent households are net-polluters, there is also confounding evidence to indicate that the picture is less clear-cut.

Jephcote, Chen and Ropkins' (2016) study found statistical measures of association respectively indicate strong and moderate inverse correlations between mobile polluters and communities characterised as socially (− 0.78) or environmentally burdened (− 0.34). A fair exploration of environmental accountability considering existing societal contributions noted these moderate and positive spatial structuring of community emission contributions, to prevail across Leicester (UK) (R2 = 0.47). The city's greatest polluters reside predominantly within affluent communities located along the city's periphery, whereas those creating the least emissions resided in central locations, and experience a range of socio-environmental health burdens. Intra-urban daily commute flows were identified to be centrically focused, with private vehicle commuter journeys from affluent polluting communities passing and terminating near less affluent neighbourhoods. The less affluent areas use active ('green') travel modes, although any health benefit may be offset by increased periods of environmental exposure. While some inner-city communities moderately contributed towards their environmental demise, these contributions were substantially outweighed by those made from external communities, whom appear to largely avoid the social, environment and physical cost of their actions. In its current state, the city's traffic management strategy seemingly operates in an environmentally unjust manner (Jephcote, Chen and Ropkins, 2016).

This study complements at a local level analysis by Barnes and Chatterton (2017) which demonstrates a clear environmental injustice issue in relation to road traffic emissions in England and Wales, with areas with the lowest proportion of households in poverty having on average higher emission factors per household than areas in the highest percentile. Further analysis also reveals that those areas in the lowest percentile, i.e. high SES, own the most vehicles, including the most diesel vehicles, have on average older vehicles and drive the furthest, therefore generating the greatest total emissions and contributing disproportionately to traffic-related pollution (Barnes and Chatterton, 2017). This is contrary to previous studies (e.g. Mitchell and Dorling, 2003), which associate poorer households with the oldest, most polluting vehicles.

It is also in contrast to Vanherle and Vergeer (2016) whose analysis into the socio-economic properties of the used car market in Europe confirmed their intuition that there are important socio-economic distribution effects associated with it. Consistently in all EU countries, the used car market is more important for lower income groups. While used cars are more prevalent in lower income groups, the used cars also tend to be older. As a consequence, any policy (e.g. environmental legislation, safety, taxation) affecting (sales of) new vehicles exclusively, will generate asymmetric impacts in terms of cost and benefits over the different socio-economic groups (Vanherle and Vergeer, 2016).

Interestingly, Hackbarth and Madlener's (2016) investigation of German car buyers' preferences for alternative fuelled vehicles (AFVs) found that younger, less educated, and highly environmentally aware consumers with a high daily mileage are more likely to choose new vehicle technologies in general, while particularly plug-in hybrid electric vehicles (PHEVs) find enthusiasts also among the elderly and technophile buyers of larger cars. They also found that German car buyers are willing to pay considerable amounts for the improvement of all vehicle attributes and that this appreciation varies depending on the consumer group, and is characterized by diminishing marginal returns of improvements of vehicles' CO2 emissions, driving range, fuel availability, and recharging time (Hackbarth and Madlener, 2016).

Chatterton et al. (2016) provide an exploratory analysis of large UK datasets of energy consumed for domestic purposes and car travel, drawing on readings from over 70 million domestic energy meters and vehicle odometers. They find that energy consumption varies greatly across the UK and correlates with levels of household wealth or deprivation within geographic locations, with a minority of relatively wealthy areas consuming greater amounts of energy for both car travel and domestic uses. They argue that this prompts concerns about the equity of existing patterns of energy consumption, with consequent implications for the fairness of policies that focus on lowering aggregate energy consumption regardless of questions of responsibility and who should be required to make reductions. The authors suggest that more equitable policies would place a higher priority on targeting wealthier and high-consuming areas, especially as these households have greater resources (financial and others) that would allow them to more easily take measures to reduce their consumption (Simcock and Mullen, 2016).

Analysis of modal choice in Greece in recent years has identified that the economic crisis with its impacts on citizens' reduction of personal income and increase of unemployment can change their travel behaviour for both utilitarian and recreational trips in favour of sustainable transportation (Galanis et al., 2017), indicating that those on lower incomes are more likely to generate lower emissions. This was similar in Scotland where differences in levels of active travel remain between socio-economic groups. Most health inequalities are largely unfavourable to the most deprived groups in the population, but in the case of active travel in Scotland they run in the opposite direction, in that those living in the most deprived areas are the most likely to report active travel. Despite this, it is important that active travel is promoted regardless of SES; partly because of important health outcomes for which physical activity reduces risk and which are not strongly socially patterned, and partly for environmental co-benefits including reducing fossil fuel consumption, reducing vehicle emissions, and the preservation or enhancement of infrastructure to support walking and cycling (Olsen, et al., 2017). Tainio et al. (2017) also estimated the health effects, consumer costs and GHG emission changes of several physical activity and diet scenarios for the working age population of England and found that replacing short car trips with cycling would benefit more people with high SES.

When developing effective policy measures to reduce air and pollution, it is important to consider who is responsible for generating emissions and that policies do not inadvertently worsen conditions for those in lower SES groups.

García-Muros et al. (2017) examined whether policy to reduce air pollution in Spain may unfairly penalise low-income households. Their results show that taxes on local pollutants are more regressive than those levied on climate change pollutants. In fact, the global climate change (GCC) tax tends to be proportional because the energy used in lighting and heating, consumed mainly by low-income households, is offset by the higher spending on transport and energy by high-income households. Local air pollution (LAP) taxes tend to be more regressive because they largely affect goods that are consumed by low-income households, such as electricity and food. The increase in food prices is a key factor that explains the regressivity of the LAP tax, because this tax indirectly increases the price of food more and because low-income households spend a large proportion of their income on food (García-Muros et al., 2017).

Munford (2017) provides a unique insight into the ex-post effect that congestion charging policies have on social capital, specifically evaluating the impact that the Western Extension Zone of London's Congestion Charging scheme had on the frequency of visits to friends and family. Those who used a car to make visits prior to the implementation of the WEZ make substantially fewer visits after it is introduced, when compared to people who use other forms of travel. These results are robust to controlling for available socio-economic information, including age, gender, occupational status, and changes in income. In addition, those who initially drove a car make, on average, more trips than other individuals. The implementation of the WEZ had the greatest impact on the frequency of visiting friends (in terms of magnitude and significance), when compared to visits to family. However, as above, visits to family were also statistically significantly reduced as a result of the WEZ. What is most startling about the results presented is the reduction in visits to act as a carer. This is consistent for both visits to people within the WEZ and for visits by WEZ residents to care for non-residents and may lead to a higher demand for more formal healthcare services, such as doctors and hospitals (Munford, 2017)

The sustainable transport discourse may be used to support policies that are potentially socially inequitable. However, also the distribution of the environmental burden of, among other things, transport activities may be unjust, as the environmental justice literature maintains. Although the size and even the sign of effects varies across cities and regions, there is some evidence that low-income and minority communities are exposed to higher levels of noise and air pollution. This is one side of the (distributive) justice coin. The other side concerns the morally proper distribution of transport benefits, in which social inclusion is often not the main concern. In contrast, inclusion is a core concept in part of the accessibility literature, which emphasises that people need access to activities and facilities in order to fully participate in society. Reconciling accessibility with sustainability requires proximity and this might require rethinking consumption and production patterns. Several existing ideas about sustainable mobility dovetail with the accessibility narrative, even though the contribution to social justice is often not explicitly mentioned. It might be a good idea to continuously favour the use of public transport and bicycles in cities. Even though the expected impact on greenhouse gas emissions is only little, such policies will contribute to the quality of life of those living in urban areas, especially with respect to the socially weakest. This does not mean that all vulnerable groups will benefit from car discouraging policies, but by offering public transport and bicycle paths as a public service, all segments of the population would face additional travel opportunities. Road safety too can benefit from such measures, while compact urban planning may improve accessibility by limiting distance between origins and destinations of journeys (Boussauw and Vanoutrive, 2017).

Gössling (2016) builds on on-going discussions about necessary changes in urban transport systems to reduce accidents, congestion, air and noise pollution, and to improve social interactions, liveability and amenity values in cities. These issues have been discussed in relation to different transport modes, and been put in the context of academic debate about the ‘just city’. Findings suggest that considerable injustices exist with regard to exposure, space, and time. Health impacts related to accidents, noise, and pollutants caused by motorized traffic are significant, and often exceed the levels recommended by health authorities, or legislated thresholds (noise, air pollution). Similar findings have been presented with regard to space allocation and the valuation of time, with the overall result that injustices are an outcome of unequal distributions of the burdens and benefits associated with transport systems. Cars and motorcycles were found to contribute disproportionally more often to accidents, distress, noise, pollutants, smell and climate change, while pedestrians and cyclists were identified as the most affected, along with children and populations living close to major roads. Pedestrians and cyclists were also found to be disadvantaged in terms of time valuation and prioritization in traffic; individual motorized transport, on the other hand, profits from the largest share of transport infrastructure. Although not addressed in this study, evidence presented elsewhere in this report have indicated that those in lower SES are least likely to have access to a car or motorcycle and may be more likely to use sustainable means. In light of these findings, it is argued that the sustainable mobility paradigm will profit from the inclusion of an ‘urban transport justice’ perspective (Gössling, 2016).

In summary, there is some (largely UK-based) evidence to indicate that those in lower SES groups are more likely to be subject to exposure to emissions created by more affluent individuals or households, however contradictory evidence (from Europe) to suggest that second-hand, and thereby older, cars are favoured by lower SES groups. Other evidence indicates that those in SES groups may be more likely to use more sustainable/less polluting means of travel. There is no clear evidence associated with lifestyle factors and occupation and emissions generation and no real evidence regarding use of solid-fuel burning and SES. Policies that seek to improve air quality should do so with a mind to redressing environmental injustice issues associated with exposure vs. generation.

6 Action to reduce exposure to noise and air pollution

- No clear evidence was found of examples of policy measures that have led to a reduction in exposure to noise/air pollution either in or apart from deprived communities.
- Instead a selection of evidence is presented which discusses potential and proposed policy measures, including both hard and soft measures like awareness raising, as well as broader urban initiatives to create more green/blue space.
- An integrated and combined approach to air and noise pollution, public health and social inequality is still in the early stages in Europe, with air quality and noise policies rarely incorporating the socioeconomic dimension.
- Joined-up policy to tackle health inequalities associated with unequal exposure to noise and air pollution, whilst ensuring that decisions outside the health sector do not have harmful or unfairly distributed impacts on public health is needed.
- Possible policies include:
  - Discourage the use of high polluting vehicles, with a phased introduction of ultra-low emission vehicles (Russell-Jones, 2017).
  - 50% conversion of open wood stoves into heat recovery wood stoves would deliver the largest benefit; heat recovery wood stove measure combined with a replacement of 10% of passenger cars below EURO 3 with hybrid vehicles would be the most cost-efficient scenario (Miranda et al., 2016).
  - Designated cycling network associated with a cycling mode share of up to 24.7% (Mueller et al., 2018).
  - Measures aimed at reducing the number of cars on the roads need to be more attractive (Mueller et al., 2018; Nieuwenhuijsen and Khreis, 2016), or driving made less attractive, e.g. speed reduction, (Perez-Prada and Monzon, 2017).
  - Awareness-raising campaigns on reducing car dependency to improve public health (Kopnina 2017), and encouraging more sustainable modes of transport.

This section presents policy measures and case studies relating to SES, air and noise pollution. No clear evidence was found on the effectiveness of specific policy measures to lead to a reduction in exposure, regardless of SES. Instead a number of studies discussed here presented examples of proposed or potential implementations. The case studies are presented to illustrate examples of policy measures that have been or are being implemented, but for which evidence to evaluate them is not yet available.

6.1 Policy measures

This report explored the relationship between health impacts from exposure to air pollution and noise and low socio-economic background. On a policy level, plans to address air and noise pollution should take the socioeconomic dimension of pollution exposure into account, tackle inequality, and protect those more at risk (WHO, 2012; Holgate 2017). Furthermore, Brunt et al (2016) have argued in favour of integrating public health in local air quality management as this would increase collaboration and engagement, improve the understanding of local air pollution problems, and support policymakers in prioritising and targeting health needs-based action, also beyond specific air pollution reduction measures. This approach could arguably be applied to noise as well.

The evidence in this report suggests that an integrated and combined approach to air and noise pollution, public health and social inequality is still early stages in Europe, with air quality and noise policies rarely incorporating the socioeconomic dimension (section 2.2). Nevertheless, policies that aim to reduce air or noise pollution could generate significant co-benefits in terms of public health, and vice-versa. However, classical end-of-pipe measures (such as various filters and catalyst) only account for a moderate improvement in air quality (Guariso, Maione and Volta, 2016); therefore, policymakers should adopt measures to encourage shifts in citizens' behaviour (e.g. claircity.eu). This could be achieved with both structural and non-structural measures.

More specifically, initiatives to tackle air pollution and protect public health should discourage the use of high polluting vehicles, with a phased introduction of ultra-low emission vehicles being one potential solution (Russell-Jones, 2017). However, Alam et al (2017) suggested that the current electric vehicle (EV) penetration is away from the desired level. Therefore, other approaches or a different policy mix are needed. In a study assessing four different scenarios based on combinations of emission reduction measures in the Grande Porto urban area (Portugal), Miranda et al (2016) found that a 50% conversion of open wood stoves into heat recovery wood stoves would deliver the largest benefit, whereas a heat recovery wood stove measure combined with a replacement of 10% of passenger cars below EURO 3 with hybrid vehicles would be the most cost-efficient scenario. Nieuwenhuijsen and Khreis (2016) argued that successful car-reduction measures and (partly) private car free cities would lead to a reduction in the need for parking and road space, providing opportunities to increase green spaces and infrastructure for active mobility – which would dramatically reduce traffic-related air pollution and noise in city centres. In this regards Kopnina (2017) argued that campaigns to raise environmental health awareness should explicitly link vehicular dependency to poor respiratory health, thus challenging 'car-culture' and encouraging citizens to switch to public transport or to active mobility.

Structural measures could involve urban planning policies aimed at promoting active transport or improving green and blue spaces, for example investments in cycling networks (Fisher et al., 2017). In this regard, Mueller et al. (2018) studied the potential associations between cycling network length, mode share and associated health impacts across European cities and found that a designated cycling network is associated with a cycling mode share of up to 24.7%. This would result in net health benefits (they estimated that if all the 167 cities achieved the maximal cycling mode share of 24.7% could result in over 10,000 premature deaths avoidable) and, furthermore, these health benefits would be larger among people who are less physically active and who have high incidence rates for non-communicable diseases). Moreover, improving cycling facilities and reducing the rate of violent crimes tend to increase the usage of bike sharing systems (Sun et al., 2017; Sun and Mobasheri, 2017). In light of the evidence in this report, this could also lead to a reduction of health inequalities due to air and noise pollution exposure due to socioeconomic factors.

There is concurring evidence that, in order for these measures to be effective, a more systematic and integrated approach to urban, transport, environmental and energy planning has to be adopted (Lah, 2017a; Nieuwenhuijsen et al., 2017; Böhme et al., 2015; European Lung Foundation and European Respiratory Society, 2013). A more integrated approach could help policymakers to tackle the risk that

an increase in urban and economic development might lead to an increase in air pollution, and therefore to an increase in health hazards (Mesjasz-Lech 2016)[32].
Cariolet et al., (2018) have applied a GIS-based method to conduct a quantitative assessment of Greater Paris' capacity to cope with traffic-related air pollution. In this study, they identified areas where the capacity to decrease emissions need to be improved and demonstrated that the capacity to decrease concentrations is low in inner Paris, thus emphasising the need to maintain potential ventilation channels.

Moreover, co-benefits of public health and air and noise pollution reduction measures could be derived also from broader urban initiatives to create more green/blue space and trees. Indeed, city planners have been increasingly considering green areas and the influence of their distribution in urban neighbourhoods on health-related behaviour, physical and mental health (WHO, 2012). As an example of how green areas can create co-benefit, Alcock et al (2017) suggested that people's respiratory health in highly polluted areas improve with the expansion of tree cover. Furthermore, Nieuwenhuijsen (2016) pointed out that physical activities in green spaces have added benefits and that cyclists generally prefer to cycle in greener areas (which could potentially support the uptake of cycling in cities). This is relevant because, in order to have a successful uptake, measures aimed at reducing the number of cars on the roads need to be more attractive (Mueller et al 2018; Nieuwenhuijsen and Khreis 2016). It has been suggested that speed reduction strategies could contribute to this goal, as lowering speed limits makes roads less attractive to drivers and that they lower free-flow speed (Perez-Prada and Monzon, 2017). Moreover, efforts could be dedicated to increasing “well-being” walking routes to school by reducing car use on school routes, with significant benefits on children's health (Alvarez-Pedrerol et al. 2017; Nieuwenhuijsen and Khreis, 2016).

Some authors have underscored the need to focus campaigns on reducing car dependency to improve public health (Kopnina 2017); other awareness-raising activities could be focussed on encouraging more sustainable modes of transport. In relation to this issue, a study by Bösehans and Walker (2016) showed that a significant proportion of bus users (approximately 19-41%) might be willing to switch to even more sustainable and active means of transport. Although this would not always be possible, campaigns targeted and tailored to specific groups could aim at promoting this shift, which would in turn improve public health and environmental quality. Moreover, campaigns or specific policy measures could be tailored on individual target groups to include social aspects of mobility in transport policy (UMID, 2011). Yet, it has been argued that new forms of communications between experts, citizens and stakeholders need to be found to successfully implement health-promoting policies (Nieuwenhuijsen et al. 2017). The Health Impact Assessment tools developed by the World Health Organization (WHO) can help experts to improve population health in particular regions of Europe (Kowalski, Kowalska and Kowalska, 2016); however, Nieuwenhuijsen et al. (2017) maintain that there is still a lack of participatory, integrated health impact assessment methods that include a quantification of the full-chain from source through health impact.

As stated in the SEP (2016) report (p. 12), and still considered relevant here: “according to the WHO, inter-sectoral policymaking is crucial to progress on the social determinants of health. The EU follows a Health in all Policies (HIAP) approach to policymaking that emphasises the importance of all public policies and decisions in influencing health impacts. The HIAP approach recognises that it is not just

[32] To address this issue, Poland has developed and implemented programmes based on the concept of green logistics, which aims at eliminating the clash between the environmental and economic goals.

decisions within health policymaking that affect public health, but also decisions within areas such as taxation, education and the environment. Extending this approach into national, regional and local policy means that EU Member States must adopt joined-up policy initiatives to tackle the health inequalities associated with unequal exposure to noise and air pollution, whilst ensuring that decisions within policy sectors outside the health sector do not have harmful or unfairly distributed impacts on public health."

With regards to inter-sectoral policymaking, there is evidence of the benefits of green space in tackling air and noise pollution and addressing social inequities. The IEEP report "The Health and Social Benefits on Nature and Biodiversity Protection" (ten Brink et al., 2016) reviews the pathways through which vegetation affects air quality, particularly through the absorption of gaseous pollutants and the deposition of particulates on vegetation[33] (p. 9). Moreover, vegetation can also redistribute and absorb sound energy. In particular, the report indicates two ways in which vegetation reduces noise pollution: reduction at source and through anti-propagation (insulation of buildings, building noise barriers, etc.) (p. 59). Furthermore, although there is still a limited understanding of how the natural environment can contribute to reducing social inequality, green space provides opportunity for interaction and for engaging stakeholders with different health conditions and from different social backgrounds. For example, in the IEEP report the Walkability Project in Wales (ten Brink et al., 2016) (UK) is presented as an example of initiatives where nature can become a "health asset" for the wider community (p. 119).

6.2 Case studies

Three geographical case studies (one in London, UK, two projects in Germany and one in Bilbao, Spain) are presented to illustrate examples of policy measures that have been or are being implemented, but for which evidence to evaluate them is not yet available. The London example is focused on air pollution, Bilbao on noise pollution and the German projects refer to both air and noise.

6.2.1 *London: Schools and air pollution*

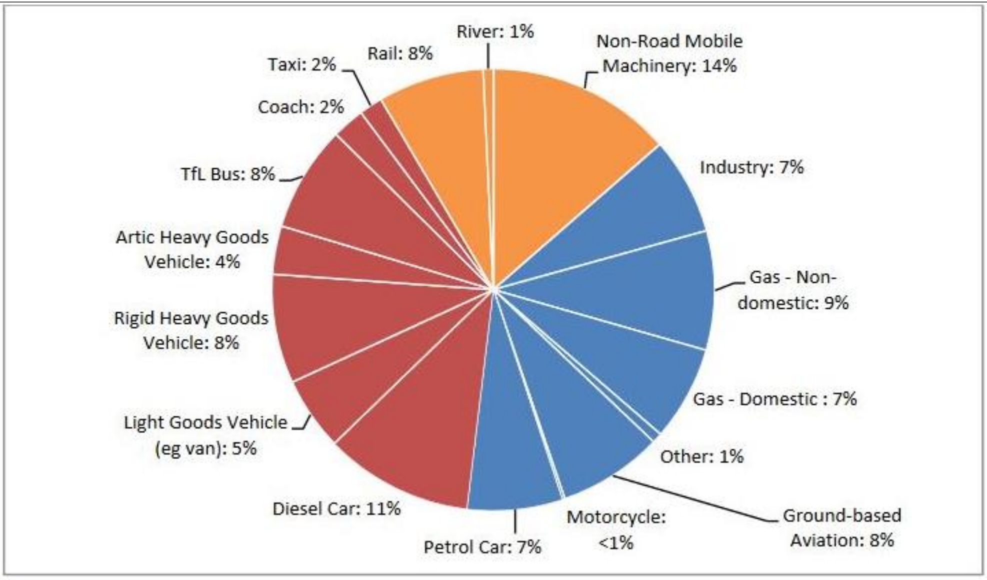
London has a major air pollution problem, with diesel exhaust being a major contributor (40% of London's NOx emissions are linked to diesel road traffic) (**Error! Reference source not found.**).

In order to reduce the concentration of NO_2 (which has been broadly stable in the past few years) and avoid breaching legal limits, the Mayor of London introduced measures such as a Toxicity Charge for older and dirtier cars in central London, Low Emission Bus Zones, and announced the introduction of Ultra-low Emission zone (to be launched in April 2019). In London air quality alerts are displayed at many public locations and sent to train stations and bus stops when pollution levels reach dangerous levels, advising vulnerable groups to take precautionary measures. However, more action is needed to reduce exposure of vulnerable groups to pollution. With schools across the city located near roads with illegal and harmful levels of air pollution, children are exposed to pollution both in the short and long-term, thus increasing the likelihood of developing respiratory and cardiovascular diseases. This is why the Mayor of London recently decided to improve and extend the air alerts measure to include schools - GPs' surgeries and care homes will be included in the near future. Furthermore, in 2017 Sadiq Khan also announced £250,000 funding for air quality audits in 50 London primary schools[34], which have been carried out by global transport and environment consultancy WSP. The selected 50 schools are part of a

[33] Although it must be underlined that vegetation can also reduce dispersal of pollutants, thus contributing negatively to air quality.
[34] See https://www.london.gov.uk/press-releases/mayoral/mayors-air-quality-audits-to-protect-london-kids

pilot, which, if successful, will lead to the extension of the audit to every school located in an area of high pollution. Finally, a £750,000 grant fund for planting trees across London within the broader London Greener City Fund[35], delivered 29 projects to plant around 41,000 trees between January and March 2017[36]. In partnership with the Conservation Volunteers, 10,000 trees were allocated among London's schools and community groups[37]. The issue of exposure to pollution of vulnerable groups, particularly children, is receiving increasing attention by civil society and the public. Recently, two NGOs active in the UK – ClientEarth and British Lung Foundation joined together to launch the Clean Air Parents' Network to promote air quality awareness among parents. A new study by ClientEarth reveals that 60% of UK parents want traffic diverted away from school gates at the beginning and end of school day, with just 13% opposed. Moreover, 70% of parents supported the idea of sending alerts to schools on high pollution days, as well as giving guidance regarding the appropriate measures to be taken.

Figure 11: London's NOx Emissions (London Assembly, Environment Committee, 2015)



London Atmospheric Emissions Inventory and Transport Emissions Road Map

Road diesel emissions are in red, other diesel in orange, and other or mixed fuels in blue

6.2.2 *Umwelt & Gesundheit (2 projects):*

In Germany, the Environmental Justice in Urban Areas project (2012-2014) and a follow-on project (2015-2017) tackled health impacts in poorer neighbourhoods with an environmental justice lens.

Environmental Justice in Urban Areas (2012-2014)

The project *Environmental Justice in Urban Areas - development of practically oriented strategies and measures to reduce socially unequal distribution of environmental burdens* (2012-2014)[38] developed an integrated monitoring approach that integrated information on the state of the environment, social and health conditions. It also conducted an evaluation study of the potential of formal and informal measures to improve the state of the environment with the aim of reducing health impacts based on the principles of environmental justice and socio-spatial differentiation. These measures were

[35] See https://www.london.gov.uk/what-we-do/environment/parks-green-spaces-and-biodiversity/greener-city-fund
[36]See https://www.london.gov.uk/what-we-do/environment/parks-green-spaces-and-biodiversity/trees-and-woodlands/tree-planting-grants
[37] https://www.london.gov.uk/what-we-do/environment/parks-green-spaces-and-biodiversity/trees-and-woodlands
[38] https://www.umweltbundesamt.de/en/publikationen/umweltgerechtigkeit-im-staedtischen-raum

developed and tested in five municipalities in Germany (Berlin district Friedrichshain-Kreuzberg, cities of Bottrop, Düsseldorf, Mülheim/Ruhr, Nuremberg).
The results identified the following broad areas for action:

- Reduction of noise exposure caused by traffic, e.g. by using noise-reducing solutions for road surfaces/landscaped tramlines, installing soundproof windows, introducing speed limits;
- Air pollution control and the urban climate, e.g. transit bans for trucks/traffic control measures, reducing overheating by promoting green areas, reducing the number of local heating points;
- Energy-efficient retrofitting of existing buildings, e.g. insulation, consulting on energy refurbishment and healthy indoor air;
- Environmentally-friendly mobility, e.g. raising the attractiveness of public transport, promoting pedestrian and bicycle traffic, promoting electromobility;
- Family, child, youth and senior-friendly neighbourhood development, e.g. in terms of street planning, reducing hazards in traffic areas, creating barrier-free environments;
- Development of green spaces and play areas, e.g. preserving and creating small green areas, playgrounds and exercise areas, creating temporary green interim area usage, roof and facade greening, de-sealing of courtyards;
- Environmental and health education, e.g. creating areas where people can experience nature and the environment, providing environmental and health information to adults (Böhme et al. 2015, p. 8)

Moreover, a series of recommendations were developed for municipalities and federal and state governments, including: to improve the integration of administrative actions; to improve monitoring; to better convey the relevance and the value of environmental justice; to better develop objectives, measures and projects; to better implement planning and environmental law instruments; and to improve public participation and ensure the involvement of those affected.

Pilot project on environmental justice in German municipalities (2015-2017)

Following on from the first project, another pilot project with a focus on environmental justice looked at socially disadvantaged neighbourhoods in Germany suffering from a high number of environment-related health risks[39]. The research project by German Institute of Urban Affairs (DIFU) tested key elements of a strategic approach to achieving environmental justice in three pilot municipalities (Kassel, Marburg and Munich). The areas were selected because of their exposure to multiple burdens, including noise, air pollution and social problems and for their lack of green areas. The working group included representatives from the environmental and nature conservation sectors, health sector, urban development sector, as well as officials representing national and federal governments.
As explained on the project website, the project was composed of three modules:

- Provision of activating support for the three pilot municipalities of Kassel, Marburg and Munich;
- Creation of a "Local Environmental Justice" toolbox for municipalities providing definitions, background information, checklists, advice on implementation and practical examples;
- Performance and online documentation of a stocktaking event "Local Environmental Justice".

[39] https://www.umweltbundesamt.de/en/pilot-project-on-environmental-justice-in-german

6.2.3 *Bilbao: Soundscape planning as a complement to environmental noise management (2016, ongoing)*

The City Council of Bilbao was a pioneering municipality in noise management, becoming the first local government in Spain with its own Noise Ordinance, Noise Map and monitoring system. However, the initial approach to the policy on noise was of a clearly sector-based nature and not proactive. A new approach was taken in 2016 by adding value to the city and its spaces including management of the noise factor. To this end, the City Council is deploying a Sound Strategy, which is intended to make Bilbao a space where sounds coexist, improving urban comfort and its people's quality of life.

In noise control, sound is a waste product managed to reduce the immission of sounds that cause human discomfort. The soundscape approach, by contrast, considers the acoustic environment as a resource, focussing on sounds people want, or prefer (Botteldooren et al., 2013). Quiet is not a core condition for acoustic preference in the outdoor acoustic environment, but congruence of soundscape and landscape is. So too is that sounds that are wanted are heard above, not masked by, sounds that are unwanted in that place and context (Aspuru et al., 2011).

The Strategy is based on the following principles (Garcia et al., 2016):

- Integrated: considering all the variables and all role -players;
- Flexible: adjusted to the reality of available city resources and the relative importance of the noise-related topics to be dealt with;
- Balanced: place the focus on coexistence, multi-purpose uses and the equitable nature of any solutions and protocols developed;

The implementation of the Strategy is taking the following steps (Garcia et al., 2016):

- Identification of Acoustic performance units (APU): Areas with the same acoustic frame (type of buildings, sound sources and social characteristics);
- Sound diagnosis of APUs. After identifying these Acoustic Action Units and performing diagnostic sound testing on them through a SWOT analysis, CANVASES are developed with the participation of the people to define the sound-related actions of interest in each Action Unit. Arising from these CANVASES are many different actions which will be organized into types which respond to the same protocol for action;
- Sound strategic definition. Definition of actuation and protocols;
- Pilot cases. Implementation of pilot cases (end of 2017).

In previous actions the soundscape approach was already taken in Latorre Square (QUADMAP project). The renovation works of the square were executed at the end of 2012. Six months later, the place was re-assessed. The renewal of the square has led an increase in user satisfaction. The average time that users are in this place has doubled and 97% of respondents consider the square as pleasant (increasing by 69 percentage points from the pre-renovation phase). The new design has helped improve the comfort index by 1.5 points (on a scale of twelve) and reduced noise levels by 3 dBA (at the height of a person sitting on a bench). The design improves other comfort parameters. For example, the square is considered more calm, safer and cleaner (increase of around 41% users' perceptions), more accessible and visually pleasing (increase of 50%).

7 Summary and recommendations

7.1 Summary

- This review has identified and synthesised evidence from a wide range of sources in response to the objectives set by the EEA.
- Links between exposure to noise and air pollution and SES are highly complex and present significant research and policy challenges.
- Evidence indicates that there is a relationship between exposure to both air and noise pollution and SES, largely associated with residential location in urban areas, with road traffic the major source.
- Other urban/environmental stressors can contribute/exacerbate health impacts in low SES groups, including lifestyle factors and occupational exposure.
- Vulnerable individuals within low SES groups exposed to air and noise pollution can experience increased health impacts.
- Some evidence to suggest that there is an environmental injustice issue regarding emissions generation, but little evidence regarding ability of more affluent people to avoid pollution, except with regard to choice over residential location.

7.1.1 *Section 2: Policy context*

Review of environmental policy

A review of relevant EU environment policies was undertaken to determine the extent to which any mention of social inequality factors has been included. The evidence from the content analysis showed that, overall, the inclusion of socioeconomic factors within both over-arching environmental objectives and more sector-specific environmental directives is mixed. In particular, strategic and longer-term documents, albeit at different degrees, generally refer to societal challenges and link environmental protection to social inequality; by contrast, the consideration of socioeconomic factors within sector-specific directives is weaker. The analysis suggests that while higher-level and longer-term documents within an environmental scope are likely to include references to socioeconomic factors, with some of them also looking at the interplay between social deprivation and exposure, the environmental directives do not integrate these aspects to date.

Review of SES proxies

A review of historical and current SES proxies revealed similarities and discrepancies throughout their evolution. As the term suggests, its component parts are generally economic and social metrics, primarily income/poverty, employment and education. However, some sources also use social exclusion including access to services, discrimination and health metrics. More recent examples have also introduced living environments as well, however care should be taken that metrics used as determinants of SES are not in fact effects of SES. Hence, proxies such as the English IMD, which comprise different ‘domains’ can be useful for studies aiming to isolate specific determinants or to avoid autocorrelation of effect. It should be noted that SES proxies do not just vary temporally; studies undertaken in different countries will use different indices depending on available metrics.

7.1.2 *Section 3: Update to SEP report*

In updating the SEP report the review has focused on changes in global/European trends, spatial scales of impact, types of noise and air pollution, types of health impact and key sources of noise and air pollution. In the relatively short period since the SEP report was prepared a number of key reviews have been published that provide a detailed and comprehensive overview of health impacts (notably, The Lancet Commission on pollution and health (Landrigan et al., 2017) and analyses of the Global Burden of Diseases Study 2015 (e.g. Cohen et al., 2017). In addition, the latest EEA 'Air quality in Europe' report (EEA, 2017) provides the latest emission trends).

Global/European trends

In terms of global and European trends, in developing countries population exposed to environmental noise is expected to grow dramatically, coinciding with global urbanisation hotspots. In Europe, however, exposure to noise pollution is decreasing in the period 2007-2012. The latest data (2012-2017) has only just been released and hence no analysis has yet been possible. Concentrations of key pollutants (PM, O_3) continue to increase globally, and across Europe many countries continue to exceed EU limit values relating to human health (PM, O_3, NO_2, BaP). Despite continued exceedences of the EU limit values, total emissions of most pollutants are decreasing across the EU, although the pattern is heterogeneous between countries.

Spatial scales of impact

Spatial analysis of environmental inequality lacks a consistent, easily applicable, and empirically driven method of scale selection for both air and noise. Reported outcomes from studies dedicated to empirically demonstrate a direct relationship between SES and exposure to environmental noise presented a heterogeneity of findings partly explained by its dependency on the spatial scale and population assignment strategies. Spatial scales of exposure to air pollution are also complex and relate primarily to urbanisation and direct proximity to source, although local variabilities are inherent. Differences in exposure over different spatial scales is furthermore related to age and SES, contributing to environmental injustice through increased risk and vulnerabilities. Assessing spatial scales of exposure is further complicated by determination of personal exposures including residential, workplace/school and commuting.

Types of noise and air pollution

Types of noise pollution have not changed since the SEP report and largely relate to source, which have also remained the same. Outside of the legislated air pollutants covered by the Ambient Air Quality Directive (2008/50/EC) and National Emissions Ceiling Directive (2016/2284/EU), new and potentially problematic pollutants are coming to the fore, including microplastics and unregulated chemical pollutants. Regulated emissions of ammonia are also increasing across Europe.

Types of health impact

The health and well-being endpoints considered for noise exposure assessment were annoyance, sleep disturbance, cognitive performance, diabetes, hypertension, cardiovascular and cerebrovascular disease and mortality. About 85% of the burden of annoyance and sleep disturbance is related to road traffic noise, of which about 70% occurs in the agglomerations. Ambient air pollution-related premature deaths are attributed to ischaemic heart disease (IHD) and stroke, chronic obstructive pulmonary disease (COPD), acute lower respiratory infections (LRIs) and lung cancer with cardiovascular diseases representing the largest impact of air pollution. Specific causal associations have been established between $PM_{2.5}$ pollution and myocardial infarction, hyper-tension, congestive heart failure, arrhythmias, and cardiovascular mortality. Causal associations have also been established between $PM_{2.5}$ pollution and COPD and lung cancer. Emerging evidence suggests that additional causal associations may exist between $PM_{2.5}$ pollution and several highly prevalent NCDs, including diabetes, decreased cognitive function, attention-deficit or hyperactivity disorder and autism in children, and neurodegenerative disease, including dementia, in adults. $PM_{2.5}$ pollution may also be linked to increased occurrence of premature birth and low birthweight and some studies have reported an association between ambient air pollution and increased risk of sudden infant death syndrome, although these associations are not yet firmly established (Landrigan et al., 2017). Associated with the continuing increase in global concentrations of pollutants, particularly in developing countries in south-east Asia, there is an increasing trend in global mortality and morbidity with a 50% increase in global deaths predicted between 2015 and 2050 (Landrigan et al., 2017).

Key sources of noise and air pollution

Source contributions of air pollutant emissions have not changed dramatically since the publication of the SEP report. Collectively 'commercial, institutional and households' are the main source of PM_{10} (35.41%) and $PM_{2.5}$ (57.36%) in EEA countries. For PM_{10}, this is followed closely by industry (32.47%), with smaller contributions from agriculture and transport. For $PM_{2.5}$, road transport and industrial processes contribute 11.33% and 9.95% respectively. Energy production and distribution (60.08%) dominates emissions of sulphur oxides (SOx). Road transport generates 37.93% NOx emissions in the EEA-33, with energy production and distribution contributing 20.83%, followed by 'commercial, institutional and households' (13.93%) and energy use in industry (12%). 93.88% ammonia emissions are from agriculture, which is an increasing source of secondary PM.

In terms of exposure, road traffic is the main source of air and noise pollution in urban areas, where population density is highest and therefore more individuals are at risk. Rail, aircraft noise and industrial noise are the other key noise sources. Non-exhaust emissions are also a significant source of air pollution, as are non-road traffic sources e.g. rail and shipping. In some areas domestic wood- and other solid fuel-burning is an increasingly problematic source. Localised exposure to emissions from municipal solid waste incineration and waste treatment plants, industrial sources and agricultural emissions are also reported.

7.1.3 *Section 4: Impacts of socioeconomic status on vulnerability to exposure to noise and air pollution*

An analysis of the evidence relating to exposure of different socioeconomic groups to noise and air pollution confirms the SEP report findings that there are multiple, sometimes interrelated, factors at play, and some inconclusive and contrary evidence to suggest that those in the lowest socioeconomic groups may not always be the most affected, depending on sources and scales of impact. In identifying the relative impacts of noise and air pollution it is worth noting that people's perceptions of traffic noise and air pollution are intertwined because they have common sources, therefore, simultaneously testing noise annoyance and perceived air pollution may suppress the effect of the latter (Dzhambov et al., 2018). Furthermore, as existing evidence suggests a possible combined effect of air pollution and noise on health, the established association between air pollution and life satisfaction may partly reflect the synergistic effect of noise. Further studies could control for this effect and also look at the effects of air pollution or noise on a finer temporal scale (Orru et al., 2016).

Factors that help determine the exposure of different socioeconomic groups

Understanding the metrics used to define SES is key to comparing studies which examine relative exposure. As Table 1 showed there are many proxies for SES and studies vary depending on which metrics are available at the spatial scale under examination. Unequal distribution to air pollution exposure according to SES groups is therefore complex in European cities and no general pattern was observed to exist, but rather inequalities need to be specifically assessed in each city. It is also important to take into account both individual- and neighbourhood-SES in order to fully describe and understand the complexity of current patterns of social inequalities relating to air pollution (Temam et al, 2017).

Generally, where people live is a major driver for disparities relating to exposure to noise and air pollution, with higher exposure found most commonly in urban areas. Urbanisation is also more specifically related to higher traffic emissions and noise, increased heat and reduced access to green spaces, which are all contributing factors (see section **Error! Reference source not found.**). Those in lower SES groups may also have reduced accessibility to services, including public transport and may be more reliant on sustainable modes, such as walking. It was suggested in the evidence reviewed that the health benefits of active modes may be outweighed by additional exposure, however other studies have shown that exposure is higher within vehicles. Nevertheless, higher levels of noise and air pollution associated with location of residence has been disproportionately linked to adverse health effects in these lower SES groups.

Higher noise levels has been associated with lower housing values, which can be indicative of lower SES, although it is unclear whether house prices are devalued by their proximity to noise pollution or whether low value areas attract polluting activities, such as increased traffic. Interestingly air pollution was not observed to affect house price, presumably as the effects are less readily apparent. Alternatively, if purchasers are prepared to accept higher pollution levels as unavoidable consequences of living closer to facilities, then there might be no reason for the price to be affected, particularly if residents can afford to adapt properties to reduce exposure (although no evidence was found regarding this in either this or the SEP report).

Reflections on how people on higher incomes can reduce their expose and increase their resilience to air pollution or noise

There is little evidence relating to the ability of more affluent individuals or households to be able to avoid air or noise pollution. Where it exists, this primarily relates to residential location as a demonstration of their ability to implement ‘willingness to pay’ behaviour and is most clearly apparent in relation to noise exposure. As seen in the previous section, where exposure is inversely proportionate to SES, this may be as a result of the location of low-cost housing in areas subject to high levels of noise / air pollution.

This may be compounded by a higher likelihood for more polluting industries to be located in these areas and for them to be more heavily trafficked. Furthermore, the social status of these ‘deprived’ areas may be reinforced by more affluent householders exercising their ability to choose not to live in those locations, although it is unclear whether this is knowingly to avoid exposure. Conversely, areas with low exposure levels may also be associated with greater distance from busy roads and more greenspace, attracting wealthier residents and excluding those in lower socioeconomic groups.

The role that lifestyle factors and occupation may have in influencing sensitivity and vulnerability

Confounding factors relating to lifestyle are inherent in studies relating to noise and air pollution exposure in which relatively short-term (e.g. daily) temporal variations in exposure and long-term (life-course) exposure all contribute to health impacts. However, the multitude of different (indoor and outdoor) exposures and additional effects relating to lifestyle (e.g. smoking, diet) experienced within those timeframes are difficult to unpick in epidemiological studies. Within the limited evidence available, it was identified that while lifestyle may be linked to SES, lifestyle factors may be independently related to exposure and may have an additive effect in terms of health impact. Studies relating to occupational risk factors are more limited, largely as by its nature this kind of exposure is generally captured by health and safety thresholds as opposed to ambient concentrations. Furthermore, we have not included studies relating to indoor air, thereby excluding the vast majority of workplace exposures. However, higher blood pressure was observed in traffic-police compared with other outdoor workers, cardiovascular disease mortality was associated with women in routine jobs, and anxieties related to job insecurity and traffic-related exposures are likely to concur in residential and occupational contexts. Ambient air pollution should therefore be a consideration for occupational exposure in outdoor occupations. Further research is required to further understand the complexity of exposure and lifestyle effects in low SES groups.

Evidence of the increased sensitivity and vulnerability of sensitive population groups

Increased exposure to air and noise pollution in low socioeconomic groups can be compounded by the susceptibility of these groups to the effects of exposure (WHO, 2012), a combination of factors described as the “triple jeopardy” effect (Jerrett et al., 2001). Within these highly exposed, low socioeconomic groups there may also be individuals with increased sensitivity to exposure. For instance, the elderly, infants or pregnant women are more sensitive to certain pollutants (van Wee and Ettema, 2016). This effectively adds another dimension to vulnerability, which could then be considered a “quadruple jeopardy” effect. Evidence indicates that children, including prenatal, the elderly and those with existing health conditions may be more represented in lower SES groups and in areas with higher exposure to noise/air pollution and are more susceptible to the resulting health impacts. However, the evidence is not unanimous.

If people in low SES groups are more likely to be exposed to environmental hazards, then their health will be even more seriously compromised. There is also some evidence that suggest that deprivation might exacerbate the effects of environmental exposure in some cases, by making those exposed more susceptible to environmental factors, perhaps because of their impaired prior health status or because of their poorer access to health care (Marmot and Wilkinson, 2006; O’Neill et al., 2003). The combined effects of deprivation and environmental exposure are likely to be more complex than additive.

Evidence of how people of lower socioeconomic status are exposed to combined stressors

As the earlier sections have demonstrated, living in urban areas brings a complexity of interrelated issues to bear, beyond increased exposure to air and noise pollution. People with lower SES are also subject to increased vulnerabilities and sensitivity as described in section **Error! Reference source not found.**. The combination of low SES and exposure to these combined stressors is therefore of additional concern.

Generally, most of the reviewed studies demonstrate that people with lower SES tend to live in worse environmental conditions often with lower accessibility to the mitigating effects of green spaces. This is an outcome of the interaction of multiple factors. Therefore, it is highly relevant to determine the context of the analysis such as the spatial scale or the causes of inequalities. Spatial correlations between the different environmental hazards also imply that exposures will rarely occur alone; therefore more deprived populations are likely to be subject to complex exposure mixtures.

7.1.4 *Section 5: Impacts of socioeconomic status on generation of air pollution*

No evidence was found on the relationship between SES and generation of noise pollution, hence this section focuses purely on emerging evidence relating to air pollution generation. The premise of this section was to identify whether there was evidence that higher socioeconomic groups were contributing more to the generation of pollution to complement discussions on environmental injustice relating to exposure. Whilst there is evidence to suggest that more affluent households are net-polluters, there is also confounding evidence to indicate that the picture is less clear-cut.

Evidence from Jephcote, Chen and Ropkins (2016) identified environmental injustice in practice in Leicester, where the greatest polluters reside predominantly within affluent communities located along the cities periphery, whereas those creating the least emissions resided in central locations, and experience a range of socio-environmental health burdens. Intra-urban daily commute flows were identified to be centrically focused, with private vehicle commuter journeys from affluent polluting communities passing and terminating near less affluent neighbourhoods. Similarly, Barnes and Chatterton (2017) demonstrate a clear environmental injustice issue in relation to road traffic emissions in England and Wales, with areas with the lowest percentage of households in poverty having on average higher emission factors per household than areas in the highest percentile. Further analysis also reveals that those areas in the lowest percentile, i.e. high SES, own the most vehicles, including the most diesel vehicles, have on average older vehicles and drive the furthest, therefore generating the greatest total emissions and contributing disproportionately to traffic-related pollution (Barnes and Chatterton, 2017), somewhat in contrast to Mitchell and Dorling (2003) and Vanherle and Vergeer (2016). Chatterton et al. (2016) also found that energy consumption varies greatly across the UK and correlates with levels of household wealth or deprivation within geographic locations, with a minority of relatively wealthy areas consuming greater amounts of energy for both car travel and domestic uses.

There is evidence to indicate that people in low SES may be more likely to use more sustainable modes of transport, e.g. public transport, walking or cycling; but that policies that push society to move to electric vehicles as an alternative to fossil-fuelled vehicles may be considered regressive with respect to lower SES households and more fundamental questions need to be asked about mobility needs to avoid creating further injustices relating to emissions generation (Simcock and Mullen, 2016).

Whilst the literature reviewed focused mainly on transport emissions, there is also a growing trend in wealthier urban areas to install wood-burning stoves thereby adding to PM emissions among others, although this needs to be substantiated with further research. Given that these emissions will likely have a relatively localised effect and that solid-fuel burning is also a main heating source for poorer households, it is unclear whether there is a significant environmental justice issue here.

7.1.5 *Section 6: Action to reduce exposure to noise and air pollution*

Policy measures

No evidence was found of examples of policy measures that have led to a reduction in exposure to noise/air pollution either in or apart from deprived communities. Instead a selection of evidence is presented which discusses potential and proposed policy measures, including both hard policy measures and soft measures like awareness raising, as well as broader urban initiatives to create more green/blue space.

The evidence in this report suggests that an integrated and combined approach to air and noise pollution, public health and social inequality is still in the early stages in Europe, with air quality and noise policies rarely incorporating the socioeconomic dimension (section **Error! Reference source not found.**). Nevertheless, policies that aim to reduce air or noise pollution could generate significant co-benefits in terms of public health, and vice-versa. However, classical end-of-pipe measures (such as various filters and catalyst) only account for a moderate improvement in air quality (Guariso, Maione and Volta, 2016); therefore, policymakers should adopt measures to encourage shifts in citizens' behaviour. This could be achieved with both structural and non-structural measures. The ClairCity project (claircity.eu) is an excellent example of refocusing air quality policy around the needs of the citizen to achieve this aim.

Strategies and measures for implementing environmental justice in municipalities (and municipal planning) are still widely lacking. When developing Air and Noise Action Plans it would be desirable to integrate social inequalities as a priority. Environmental equity issues should be integrated in Environmental Impact Studies, in order to be able to highlight the (re) distributive effects of political decisions. Soundscapes are innovative approaches that try to integrate the way people perceive the acoustic environment, the physical parameters that define the acoustic environment and the expectations people have concerning that environment or area (e.g. expectations created when issuing a noise action plan to improve noise environment in a specific area).

In summary, EU Member States must adopt joined-up policy initiatives to tackle the health inequalities associated with unequal exposure to noise and air pollution, whilst ensuring that decisions within policy sectors outside the health sector do not have harmful or unfairly distributed impacts on public health.

Case studies

Three geographical case studies (one in London, UK, two projects in Germany and one in Bilbao, Spain) have been presented to illustrate examples of policy measures that have been or are being implemented, but for which evidence to evaluate them is not yet available.

In the case of Bilbao, an evaluation of the measure has been undertaken six months after the intervention took place, resulting in an improvement of several parameters evaluated and an increase of the user satisfaction. Nevertheless, a specific evaluation focused on health improvement and SES relation was not undertaken.

7.2 Key knowledge gaps and areas for future research

There is extensive evidence on the health effects of exposure to air pollution and an increasing body of evidence to suggest that effects may be disproportionately experienced, and even exacerbated by, those in lower SES groups. However, there are still gaps apparent in the body of research to help fully understand the interlinkages between each of the related factors. The following presents a non-exhaustive list of areas that have been identified as requiring further research.

- Emerging evidence on the health impacts of air pollution in particular need to be incorporated into this research area, especially relating to neurological effects and epigenetic effects. Added to this, a better understanding of the relative contribution of different air pollutants is necessary e.g. the additive effects of NO_2 exposure;
- Investigating the interplay between air and noise (and the multiple other stressors) that affect lower SES residents of urban areas needs to be more fully understood. The evidence has demonstrated interrelationships between the two, but the synergistic effects are unclear. While exposure to one may be associated with exposure to the other, due to shared sources, the similarities in health impacts mean it is unclear whether their effects are additive or multiplicative. More research is therefore required to establish the extent to which any of the multiple stressors are additive or multiplicative in their effects;
- Certain exposure routes appear to be little understood. For example, more detailed exposure assessment and health risk analysis of toxic substances released by industries, e.g. urban waste water treatment plants, metal industries, mines, explosives and pyrotechnics were highlighted;
- Certain occupational exposure should also be investigated with reference to ambient air quality limits. The situation of enclosed rail stations was highlighted as potential for very high exposure for workers and members of the public, however these areas fall out of scope for ambient assessment. The relationship between personal/occupational exposure and ambient thresholds should be investigated, including also noise exposure;
- There is emerging evidence of the impact of increasing domestic sold-fuel burning in urban areas, however, further studies are required to determine the relative contribution and whether there is disproportionate exposure to the resulting emissions in areas of low SES;
- There is a clear lack of evidence available evaluating the effectiveness of policy measures to reduce exposure to environmental hazards such as noise and air pollution in terms of improvements or health impacts, regardless of the SES of those exposed and a total absence of studies reporting quantitative details on the association between change in exposure due to transport intervention and human health effects on different SES subgroups. This has been recognised in other review work (e.g. Barnes and Williams, 2017), and demonstrates a necessary opportunity for further research to help policy makers target limited resources most effectively in improving public health.
- Further studies are also required to establish the link between environmental noise interventions with long-term health impacts to cover all sources of environmental noise, but particularly for aircraft and rail noise sources.

8 References

- Adler, N. E., Boyce, T., Chesney, M. A., Cohen, S., Folkman, S., Kahn, R. L., & Syme, S. L. (1994). Socioeconomic status and health: The challenge of the gradient. *American Psychologist*, 49(1).
- Aether (2017a). Updated Analysis of Air Pollution Exposure in London, Report to Greater London Authority, February 2017, Oxford.
- Aether (2017b). London's polluted schools: the social context, FIA Foundation Research Series, Paper 9, https://www.fiafoundation.org/media/460741/london-polluted-schools-lr-spreads.pdf [Accessed 15 March 2018].
- Ahern S.M., Arnott B., Chatterton T., de Nazelle A., Kellar I., McEachan R.R.C. (2017). Understanding parents' school travel choices: A qualitative study using the Theoretical Domains Framework. Journal of Transport and Health. 4, 278-293.
- Air Quality Expert Group (2017). The Potential Air Quality Impacts from Biomass Combustion, https://uk-air.defra.gov.uk/assets/documents/reports/cat11/1708081027_170807_AQEG_Biomass_report.pdf.
- Alam M.S., Hyde B., Duffy P., McNabola A. (2017). Assessment of pathways to reduce CO2emissions from passenger car fleets: Case study in Ireland. Applied Energy, 189, 283-300.
- Alcock I., White M., Cherrie M., Wheeler B., Taylor J., McInnes R., Otte im Kampe E., Vardoulakis S., Sarran C., Soyiri I., Fleming L. (2017). Land cover and air pollution are associated with asthma hospitalisations: A cross-sectional study. Environment International, 109, 29-41.
- Alvarez-Pedrerol M., Rivas I., López-Vicente M., Suades-González E., Donaire-Gonzalez D., Cirach M., de Castro M., Esnaola M., Basagaña X., Dadvand P., Nieuwenhuijsen M., Sunyer (2017). Impact of commuting exposure to traffic-related air pollution on cognitive development in children walking to school, Environmental Pollution, 231,837-844.
- Aspuru, I., Garcia, I., Herranz-Pascual, K., Garcia-Borreguero, I. (2011). Understanding Soundscape as a specific Environmental Experience: Highlighting the importance of context relevance. Proceedings of Meetings on Acoustics 14: 015004.
- Badaloni C., Cesaroni G., Cerza F., Davoli M., Brunekreef B., Forastiere F., (2017). Effects of long-term exposure to particulate matter and metal components on mortality in the Rome longitudinal study, Environment International, 109, 146-154.
- BAFU (2015). GIS-Lärmdatenbank sonBASE. Available: http://www.bafu.admin.ch/laerm/10312/10340/index.html?lang=de
- Bagordo F., De Donno A., Grassi T., Guido M., Devoti G., Ceretti E., Zani C., Feretti D., Villarini M., Moretti M., Salvatori T., Carducci A., Verani M., Casini B., Bonetta S., Carraro E., Schilirò T., Bonizzoni S., Bonetti A., Gelatti U., Serio F., De Giorgi M., Idolo A., Verri T., Covolo L., Donato F., Festa A., Limina R.M., Zerbini I., Fatigoni C., Levorato S., Monarca S., Vannini S., Donzelli G., Bruni B., Palomba G., Bonetta S., Gea M., Gilli G., Pignata C., Romanazzi V., Furia C., Codenotti R., Colombi P., Crottini S., Gaffurini L., Zagni L. (2017). Lifestyles and socio-cultural factors among children aged 6-8 years from five Italian towns: The MAPEC-LIFE study cohort. BMC Public Health, 17(1), 233.
- Barnes, J. and Williams, B. (2017) A review of evidence on the cost-effectiveness of local authority activities to reduce exposure to air pollution from road traffic. Air Pollution XXV, 211. pp. 3-13. Available from: http://eprints.uwe.ac.uk/32810.

- Barnes, J. and Chatterton, T. (2017). An environmental justice analysis of exposure to traffic-related pollutants in England and Wales. *WIT Transactions on Ecology and the Environment*, 210 (12). pp. 431-442. ISSN 1743-3541, http://eprints.uwe.ac.uk/28882/7/Barnes%20and%20Chatterton%20%25282016%2529%20An%20environmental%20justice%20analysis%20of%20exposure%20to%20traffic-related%20pollutants%20in%20England%20and%20Wales%20%2528FINAL%2529.pdf.
- Basner, M. and McGuire, S. (2018). WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Effects on Sleep. Sleep, Volume 40, Issue suppl_1, 28 April 2017, Pages A156, https://doi.org/10.1093/sleepj/zsx050.420.
- Blanes-Vidal V. (2017). Living in the Clean, Stress-Free and Quiet Countryside: Does the Reality Match the Dream? Residential Exposure to Environmental Health Stressors in the Danish Countryside, Human Ecology, 45(4), 545-552.
- Böhme, C., Preuß, T., Bunzel, A., Reimann, B., Seidel-Schulze, A., and Landua, D. (2015). Environmental justice in urban areas– Development of practically oriented strategies and measures to reduce socially unequal distribution of environmental burdens - Summary (Berlin: Federal Environment Agency - German Institute of Urban Affairs).
- Bolte G. and Fromme H. (2008). Umweltgerechtigkeit als Themenschwerpunkt der Gesundheits-Monitoring-Einheiten (GME) in Bayern. (Environmental justice as a main topic of the health monitoring units in Bavaria, Germany). Umweltmed. Informationsdienst 2, 39–42.
- Bösehans G., Walker I. (2016) Daily Drags' and 'Wannabe Walkers' – Identifying dissatisfied public transport users who might travel more actively and sustainably. Journal of Transport and Health, 3(3), 395-403.
- Botteldooren, D., Andringa, T., Aspuru, I., Brown, L., Dubois, D., Guastavino, C., Lavandier, C. et al. 2013. Soundscape for European cities and landscape: understanding and exchanging. In Soundscape of European cities and landscapes, pp. 36-43. Soundscape-COST.
- Boussauw K., Vanoutrive T. (2017). Transport policy in Belgium: Translating sustainability discourses into unsustainable outcomes. Transport Policy, 53, 11-19.
- Brainard, J.S., Jones, A.P., Bateman, I.J., Lovett, A.A., and Fallon, P.J. (2002). Modelling Environmental Equity: Access to Air Quality in Birmingham, England. Environ. Plan. Econ. Space 34, 695–716.
- Braubach, M. and Fariburn, J. (2010). Social inequities in environmental risks associated with housing and residential location—a review of evidence. European Journal of Public Health, Vol. 20, No. 1, 36–42.
- Braun-Fahrländer, C., Bolte, C., and Mielck, A. (2004). Die soziale Verteilung von Umweltbelastungen bei Kindern in der Schweiz. (The social distribution of environmental burden in children in Switzerland.) (Weinheim: Juventa).
- Briggs, D., Abellan, J.J., and Fecht, D. (2008). Environmental inequity in England: Small area associations between socio-economic status and environmental pollution. Soc. Sci. Med. 67, 1612–1629.
- 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. Int. J. Environ. Res. Public. Health 14, 873.
- Brunt H., Barnes J., Jones S.J., Longhurst J.W.S., Scally G., Hayes E. (2017) Air pollution, deprivation and health: Understanding relationships to add value to local air quality management policy and practice in Wales, UK. Journal of Public Health (United Kingdom), 39(3), 485-497.

- Brunt H., Barnes J., Longhurst J.W.S., Scally G., Hayes E. (2016) Local Air Quality Management policy and practice in the UK: The case for greater Public Health integration and engagement. Environmental Science and Policy, 58, 52-60.
- Cai Y., Hansell A.L., Blangiardo M., Burton P.R., de Hoogh K., Doiron, D., Fortier I., Gulliver J., Hveem K., Mbatchou S., Morley D.W., Stolk R.P., Zijlema W.L., Elliott P. and Hodgson S. (2017). Long-term exposure to road traffic noise, ambient air pollution, and cardiovascular risk factors in the HUNT and lifelines cohorts. European Heart Journal, 38(29), 2290-2296.
- Cantuaria M.L., Løfstrøm P., Blanes-Vidal V., 2017. Comparative analysis of spatio-temporal exposure assessment methods for estimating odor-related responses in non-urban populations, Science of the Total Environment, 605-606, 702-712.
- Carey I.M., Anderson H.R., Atkinson R.W., Beevers S., Cook D.G., Dajnak D., Gulliver J., Kelly F.J. (2016). Traffic pollution and the incidence of cardiorespiratory outcomes in an adult cohort in London. Occupational and Environmental Medicine, 73(12), 849-856.
- Cariolet J.-M., Colombert M., Vuillet M., Diab Y. (2018), Assessing the resilience of urban areas to traffic-related air pollution: Application in Greater Paris. Science of the Total Environment, 615, 588-596.
- Casas L., Cox B., Bauwelinck M., Nemery B., Deboosere P., Nawrot T.S. (2017). Does air pollution trigger suicide? A case-crossover analysis of suicide deaths over the life space. European Journal of Epidemiology, 32(11), 973-981.
- Cavailhès, J. (2005). Le prix des attributs du logement. Econ. Stat. 381, 91–123.
- Chatterton, T., Anable, J., Barnes, J. and Yeboah, G. (2016) [Mapping household direct energy consumption in the United Kingdom to provide a new perspective on energy justice.](http://eprints.uwe.ac.uk/29047) *Energy Research & Social Science*, 18. pp. 71-87. ISSN 2214-6296. Available from: http://eprints.uwe.ac.uk/29047.
- Checa Vizcaíno M.A., González-Comadran M., Jacquemin B. (2016).Outdoor air pollution and human infertility: a systematic review. Fertility and Sterility, 106 4, 897-9040.
- Clark C. and Paunovic K. (2018). WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Cognition. Int. J. Environ. Res. Public Health 2018, 15(2), 285.
- Clifford A., Lang L., Chen R., Anstey K.J., Seaton A. (2016). Exposure to air pollution and cognitive functioning across the life course - A systematic literature review. Environmental Research, 147, 383-398.
- Cohen A.J., Brauer M., Burnett R., Anderson H.R., Frostad J, Estep K., Balakrishnan K., Brunekreef B., Dandona L., Dandona R., Feigin V., Freedman G., Hubbell B., Jobling A., Kan H., Knibbs L., Liu Y., Martin R., Morawska L., Pope C.A., Shin H., Straif K., Shaddick G., Thomas M., van Dingenen R., van Donkelaar A., Vos T., Murray C.J.L., Forouzanfar M.H. (2017). Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015, The Lancet, 389(10082), 1907-1918.
- Cournane S., Conway R., Byrne D., O'Riordan D., Coveney S., Silke B. (2017a). High Risk subgroups sensitive to air pollution levels following an emergency medical admission. Toxics, 5(4), 27.
- Cournane S., Byrne D., Conway R., O'Riordan D., Coveney S., Silke B. (2017b).Effect of social deprivation on the admission rate and outcomes of adult respiratory emergency admissions. Respiratory Medicine, 125, 94-101.
- D'Antoni D., Smith L., Auyeung V., Weinman J. (2017). Psychosocial and demographic predictors of adherence and non-adherence to health advice accompanying air quality warning systems: A systematic review. Environmental Health: A Global Access Science Source, 16(1), 100.

- De Witte, H., Pienaar, J., and De Cuyper, N. (2016). Review of 30 Years of Longitudinal Studies on the Association Between Job Insecurity and Health and Well-Being: Is There Causal Evidence? Aust. Psychol. 51, 18–31.
- Deguen S., Padilla M., Padilla C., Kihal-Talantikite W. (2017). Do individual and neighborhood characteristics influence perceived air quality? International Journal of Environmental Research and Public Health, 14(12), 1559.
- Díaz J., Linares C., Carmona R., Russo A., Ortiz C., Salvador P., Trigo R.M. (2017). Saharan dust intrusions in Spain: Health impacts and associated synoptic conditions. Environmental Research, 156, 455-467.
- Dimitrova, D.D., and Dzhambov, A.M. (2017). Perceived access to recreational/green areas as an effect modifier of the relationship between health and neighbourhood noise/air quality: Results from the 3rd European Quality of Life Survey (EQLS, 2011–2012). Urban For. Urban Green. 23, 54–60.
- Dońnguez-Berjón M.F., Gandarillas A., Soto M.J., (2016). Lung cancer and urbanization level in a region of Southern Europe: Influence of socio-economic and environmental factors, Journal of Public Health (United Kingdom), 38(2), 229-236.
- Duncan, G. J., Daly, M. C., McDonough, P., and Williams, D. R. (2002). Optimal Indicators of Socioeconomic Status for Health Research. *American Journal of Public Health*, 92(7), 1151–1157.
- Dutton, D. B., & Levine, S. (1989). Overview, methodological critique, and reformulation. In J. P.Bunker, D. S.Gomby, & B. H.Kehrer (Eds.), *Pathways to health* (pp. 29–69). Menlo Park, CA: The Henry J. Kaiser Family Foundation.
- Dzhambov A., Hartig T., Markevych I., Tilov B., Dimitrova D. (2018). Urban residential greenspace and mental health in youth: Different approaches to testing multiple pathways yield different conclusions. Environmental Research, 160, 47-59.
- Dzhambov, A., Tilov, B., Markevych, I., and Dimitrova, D. (2017). Residential road traffic noise and general mental health in youth: The role of noise annoyance, neighborhood restorative quality, physical activity, and social cohesion as potential mediators. Environ. Int. 109, 1–9.
- EEA (2010). Good practice guide on noise exposure and potential health effects (Technical report 11/2010).
- EEA, 2014. Noise in Europe 2014. EEA Report No 10/2014. European Environment Agency.
- EEA, 2017. Air quality in Europe - 2017 report.
- ETC/ACM (2017). Noise in Europe 2017: updated assessment (ETC/ACM Technical Paper 2016/13).
- European Commission (2016). The State of European Cities 2016.Cities leading the way to a better future. Commission Staff Working Document with the agreement of UN-Habitat. Retrieved from: http://ec.europa.eu/regional_policy/en/policy/themes/urban-development/cities-report [Accessed 26/01/2018].
- European Commission, (2018). European Commission - Press release, Brussels, 19 January 2018, http://europa.eu/rapid/press-release_IP-18-348_en.htm.
- European Commission, Directorate General for Regional Policy (2011). Cities of tomorrow –Challenges, visions, ways forward. Retrieved from: http://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/citiesoftomorrow/citiesoftomorrow_final.pdf [Accessed 26/01/2018].
- European Lung Foundation and European Respiratory Society (2013). Lung health in Europe - facts and figures - a better understanding of lung disease and respiratory care in Europe.
- Faustini A., Martuzzi, M., Mitis, F. and Forastiere, F. (2010). Cross-cutting issues in Risk Assessment Susceptibility and Integrated Assessment of Health Risks. London: Imperial College School of

Medicine; 2010. INTARESE Work Package 1.5. Internet: http://www.integrated-assessment.eu/eu/sites/default/files/Susceptibile%20groups_0.pdf, consulted: 20-04-2012.

- Faustini A., Stafoggia M., Renzi M., Cesaroni G., Alessandrini E., Davoli M., Forastiere F. (2016). Does chronic exposure to high levels of nitrogen dioxide exacerbate the short-term effects of airborne particles? Occupational and Environmental Medicine, 73(11), 772-778.
- Fecht, D., Mila, C., Álvarez, M., Gulliver, J., and Tonne, G. (2017). Socio-economic and ethnic inequalities in transport-related outdoor noise at residence in London. (Zurich).
- Fernández-Camacho R., de la Rosa J.D., Sánchez de la Campa A.M. (2016). Trends and sources vs air mass origins in a major city in South-western Europe: Implications for air quality management. Science of the Total Environment, 553, 305-315.
- Filippini T., Michalke B., Malagoli C., Grill P., Bottecchi I., Malavolti M., Vescovi L., Sieri S., Krogh V., Cherubini A., Maffeis G., Modenesi M., Castiglia P., Vinceti M., (2016). Determinants of serum cadmium levels in a Northern Italy community: A cross-sectional study, Environmental Research, 150, 219-226.
- Fisher J.E., Andersen Z.J., Loft S., Pedersen M. (2017), Opportunities and challenges within urban health and sustainable development. Current Opinion in Environmental Sustainability, 25, 77-83.
- Font A. and Fuller G.W., (2016). Did policies to abate atmospheric emissions from traffic have a positive effect in London?, Environmental Pollution, 218, 463-474.
- Forns J., Dadvand P., Esnaola M., Alvarez-Pedrerol M., López-Vicente M., Garcia-Esteban R., Cirach M., Basagaña X., Guxens M., Sunyer J. (2017). Longitudinal association between air pollution exposure at school and cognitive development in school children over a period of 3.5 years. Environmental Research, 159, 416-421.
- Galanis A., Botzoris G., Siapos A., Eliou N., Profillidis V. (2017). Economic crisis and promotion of sustainable transportation: A case survey in the city of Volos, Greece. Transportation Research Procedia, 24, 241-249.
- Gallego E., Roca F.J., Perales J.F., Guardino X., Gadea E., Garrote P. (2016). Impact of formaldehyde and VOCs from waste treatment plants upon the ambient air nearby an urban area (Spain) Science of the Total Environment, 568, 369-380.
- Galloway et al., (1974). Population distribution of the United States as a function of outdoor noise. US Environmental Protection Agency Report No. 550/9-74-009. Washington, D.C., USA.
- Garcia, I., Rincon, E., Santander, A., Herranz-Pascual, K. (2016). Bilbao Sound Strategy: A Comprehensive, Flexible and Balanced Approach. INTER-NOISE and NOISE-CON Congress and Conference Proceedings 253: 4512-4522.
- García-Muros X., Burguillo M., González-Eguino M., Romero-Jordán D. (2017). Local air pollution and global climate change taxes: a distributional analysis for the case of Spain. Journal of Environmental Planning and Management, 60(3), 419-436.
- García-Pérez J., Morales-Piga A., Gómez-Barroso D., Tamayo-Uria I., Pardo Romaguera E., López-Abente G., Ramis R. (2016a) Residential proximity to environmental pollution sources and risk of rare tumors in children. Environmental Research, 151, 265-274.
- García-Pérez J., Morales-Piga A., Gómez-Barroso D., Tamayo-Uria I., Pardo Romaguera E., Fernández-Navarro P., López-Abente G., Ramis R. (2016b). Risk of neuroblastoma and residential proximity to industrial and urban sites: A case-control study. Environment International, 92-93, 269-275.
- García-Pérez J., Morales-Piga A., Gómez J., Gómez-Barroso D., Tamayo-Uria I., Pardo Romaguera E., Fernández-Navarro P., López-Abente G., Ramis R., (2016c). Association between residential proximity to environmental pollution sources and childhood renal tumors. Environmental Research, 147, 405-414.

- Gautier C., Charpin D. (2017). Environmental triggers and avoidance in the management of asthma. Journal of Asthma and Allergy, 10, 47-56.
- Gawda A., Majka G., Nowak B., Marcinkiewicz J. (2017). Air pollution, oxidative stress, and exacerbation of autoimmune diseases. Central European Journal of Immunology, 42(3), 305-312.
- Gianicolo E.A.L., Mangia C., Cervino M., (2016). Investigating mortality heterogeneity among neighbourhoods of a highly industrialised Italian city: a meta-regression approach, International Journal of Public Health, 61(7), 777-785.
- Giannadaki D., Giannakis E., Pozzer A., Lelieveld J., (2018). Estimating health and economic benefits of reductions in air pollution from agriculture, Science of the Total Environment, 622-623, 1304-1316.
- Giering, K., Guski, R., Klein, T., Möhler, U., and Schreckenberg, D. (2017). Willingness to pay in the Rhine-Main region according to aircraft noise, railway noise, road traffic noise. (Zurich). 12th ICBEN Congress on Noise as a Public Health Problem.
- Glachant, M., and Bureau, B. (2010). Évaluation de l'impact des politiques « Quartiers verts » et « Quartiers tranquilles » sur les prix de l'immobilier à Paris. Économie Prévision 192, 27–44.
- Gössling S. (2016). Urban transport justice. Journal of Transport Geography, 54, 1-9.
- Gottschalk, C., Fleischer, J., Gräfe, L., Sobottka, A., Oppermann, H., and Benkwitz, F. (2011). Belastung einzuschulender Kinder mit Umweltschadstoffen – Ergebnisse der Schulanfängerstudie Sachsen-Anhalt (Burdening of preschool children with environmental pollutants – results of the school beginners study Saxony-Anhalt). UMID 2, 63–69.
- Gratsea M., Liakakou E., Mihalopoulos N., Adamopoulos A., Tsilibari E., Gerasopoulos E. (2017). The combined effect of reduced fossil fuel consumption and increasing biomass combustion on Athens' air quality, as inferred from long term CO measurements. Science of the Total Environment, 592, 115-123.
- Greenpeace (2017). More than 1,000 nurseries nationwide close to illegally polluted roads, Unearthed, https://unearthed.greenpeace.org/2017/04/04/air-pollution-nurseries/ [Accessed 15 March 2018].
- Grelat, N., Houot, H., Pujol, S., Levain, J.-P., Defrance, J., Mariet, A.-S., and Mauny, F. (2016). Noise Annoyance in Urban Children: A Cross-Sectional Population-Based Study. Int. J. Environ. Res. Public. Health 13.
- Grivas G., Dimakopoulou K., Samoli E., Papakosta D., Karakatsani A., Katsouyanni K., Chaloulakou A., (2017). Ozone exposure assessment for children in Greece - Results from the RESPOZE study, Science of the Total Environment, 581-582, 518-529.
- Grundy E, Holt G. (2001). The socioeconomic status of older adults: How should we measure it in studies of health inequalities? Journal of Epidemiology & Community Health, 55:895-904.
- Guariso G., Maione M., Volta M. (2016). A decision framework for Integrated Assessment Modelling of air quality at regional and local scale. Environmental Science and Policy, 65, 3-12.
- Guevara M., (2016). Emissions of primary particulate matter, Issues in Environmental Science and Technology, 2016-January, 42, 1-34.
- Guski R, Schreckenberg D, Schuemer R. (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. 2017 Dec 8;14 (12):1539.
- Hackbarth A., Madlener R. (2016). Willingness-to-pay for alternative fuel vehicle characteristics: A stated choice study for Germany. Transportation Research Part A: Policy and Practice, 85, 89-111.
- Halonen J.I., Blangiardo M., Toledano M.B., Fecht D., Gulliver J., Anderson H.R., Beevers S.D., Dajnak D., Kelly F.J., Tonne C. (2016). Long-term exposure to traffic pollution and hospital admissions in London. Environmental Pollution, 208, 48-57.

- HCN (2011). Health Council of the Netherlands. Guideline for the identification and protection of high-risk groups. The Hague: Health Council of the Netherlands, 2011; publication no. 2011/39E. Internet: http://www.gezondheidsraad.nl/sites/default/files/201139E.pdf, consulted: 20-04-2012.
- Hlodversdottir H., Petursdottir G., Carlsen H.K., Gislason T., Hauksdottir A. (2016). Long-term health effects of the Eyjafjallajökull volcanic eruption: A prospective cohort study in 2010 and 2013. BMJ Open, 6(9), e011444.
- Hobza V., Hamrik, Z., Bucksh J. and De Clerq, B. (2017): The family affluence scale as an indicator for socioeconomic status: Validation on regional income differences in the Czech Republic. *International journal of environmental research and public health*, 14, (12).
- Hoffmann, B., Robra, B.-P., and Swart, E. (2003). Social inequality and noise pollution by traffic in the living environment--an analysis by the German Federal Health Survey (Bundesgesundheitssurvey). Gesundheitswesen Bundesverb. Arzte Offentlichen Gesundheitsdienstes Ger. 65, 393–401.
- Holgate S.T. (2017). Every breath we take: The lifelong impact of air pollution' - A call for action. Clinical Medicine, Journal of the Royal College of Physicians of London, 17(1), 8-12.
- Houthuijs D., Swart W., van Kempen E., van Beek A. and de Leeuw F. (2014). Health Impact Assessment for Europe-(partial) Uncertainty Evaluation. National Institute for Public Health and the Environment. 2014. Working document.
- Huete-Morales M.D., Quesada-Rubio J.-M., Navarrete-Álvarez E., Rosales-Moreno M.J., Del-Moral-ávila M.J., (2017). Air quality analysis in the European Union, Polish Journal of Environmental Studies, http://www.pjoes.com/pdf/26.3/Pol.J.Environ.Stud.Vol.26.No.3.1113-1119.pdf .
- Inpes (2007). Baromètre santé environnement (Inpes).
- Institute for Health Metrics and Evaluation (2013). The Global Burden of Disease: Generating Evidence, Guiding Policy – European Union and European Free Trade Association Regional Edition. Seattle, WA: IHME, http://www.healthdata.org/sites/default/files/files/policy_report/2013/The%20Global%20Burden%20of%20Disease_Generating%20Evidence%2C%20Guiding%20Poliy%20-%20European%20Union%20and%20Free%20Trade%20Association.pdf [Accessed 14 March 2018].
- Janssen, S., and Hong, J. (2017). Recent progress in the field of community response to noise, 12th ICBEN Congress on Noise as a Public Health Problem, 18-22 June 2017 (Zurich).
- Jephcote C., Chen H., Ropkins K. (2016). Implementation of the Polluter-Pays Principle (PPP) in local transport policy. Journal of Transport Geography, 55, 58-71.
- Jerrett, M., Burnett, R.T., Kanaroglou, P., Eyles, J., Finkelstein, N., Giovis, C., & Brook, J.R., (2001). A GIS - Environmental justice analysis of particulate air pollution in Hamilton, Canada. Environment and Planning A, 33(6) 955–973.
- Kamusheva M., Dimitrova M., van Boven J.F.M., Postma M.J., van der Molen T., Kocks J.W.H., Mitov K., Doneva M., Petrova D., Georgiev O., Petkova V., Petrova G. (2017). Clinical characteristics, treatment patterns, and socio-economic burden of COPD in Bulgaria. Journal of Medical Economics, 20(5), 503-509.
- Kasurinen S., Jalava P.I., Happo M.S., Sippula O., Uski O., Koponen H., Orasche J., Zimmermann R., Jokiniemi J., Hirvonen M.-R. (2017). Particulate emissions from the combustion of birch, beech, and spruce logs cause different cytotoxic responses in A549 cells. Environmental Toxicology, 32(5), 1487-1499.
- Kedron, P. (2016). Identifying the geographic extent of environmental inequalities: A comparison of pattern detection methods. Can. Geogr. Géographe Can. 60, 479–492.
- Khreis H., May A.D., Nieuwenhuijsen M.J. (2017). Health impacts of urban transport policy, measures: A guidance note for practice. Journal of Transport and Health, 6, 209-227.

- Killin L.O.J., Starr J.M., Shiue I.J., Russ T.C. (2016) Environmental risk factors for dementia: a systematic review. BMC Geriatrics, 16(1), 1-28.
- Kim, P., Evans, G.W., Chen, E., Miller, G., and Seeman, T. (2018). How Socioeconomic Disadvantages Get Under the Skin and into the Brain to Influence Health Development Across the Lifespan. In Handbook of Life Course Health Development, (Springer, Cham), pp. 463–497.
- Kleinschmit, B., Geißler, G., and Leutloff, H. (2011). Socio-spatial distribution of green spaces in Berlin. UMID Special issue II Environmental justice, 35–36.
- Klimeczek, H.-J. (2014). Umweltgerechtigkeit im Land Berlin – Zur methodischen Entwicklung des zweistufigen Berliner Umweltgerechtigkeitsmonitorings [Environmental justice in the state of Berlin – New concepts and methods of the two-stages monitoring of environmental justice]. UMID 2, 16–22.
- Kohlhuber, M., Mielck, A., Weiland, S.K., and Bolte, G. (2006). Social inequality in perceived environmental exposures in relation to housing conditions in Germany. Environ. Res. 101, 246–255.
- Kollanus V., Prank M., Gens A., Soares J., Vira J., Kukkonen J., Sofiev M., Salonen R.O., Lanki T. (2017). Mortality due to vegetation fire–originated $PM_{2.5}$ exposure in Europe—Assessment for the years 2005 and 2008. Environmental Health Perspectives, 125(1), 30-37.
- Kopnina H. (2016). Asthma and Air Pollution: Connecting the Dots. A Companion to Anthropology and Environmental Health, 142, 156.
- Kopnina H. (2017), Vehicular air pollution and asthma: implications for education for health and environmental sustainability, Local Environment, 22, 1, 38-48.
- Kopsch, F. (2016). The cost of aircraft noise – Does it differ from road noise? A meta-analysis. J. Air Transp. Manag. 57, 138–142.
- Kowalski M., Kowalska K., Kowalska M. (2016). Health benefits related to the reduction of PM concentration in ambient air, Silesian voivodeship, Poland International Journal of Occupational Medicine and Environmental Health, 29, 2, 209-217.
- Kruize, H., and Bouwman, A. (2004). Environmental (in)equity in the Netherlands - A case study on the distribution of environmental quality in the Rijnmond region - RIVM.
- Kruize, H., Driessen, P.P.J., Glasbergen, P., and van Egmond, K.N.D. (2007). Environmental equity and the role of public policy: experiences in the Rijnmond region. Environ. Manage. 40, 578–595.
- Kumar P. and Goel A., (2016). Concentration dynamics of coarse and fine particulate matter at and around signalised traffic intersections, Environmental Science: Processes and Impacts, 18(9), 1220-1235.
- Lah O. (2017a). Decarbonizing the transportation sector: policy options, synergies, and institutions to deliver on a low-carbon stabilization pathway. Wiley Interdisciplinary Reviews: Energy and Environment 6, 6, 257.
- Lakes, T., and Brückner, M. (2011). Socio-spatial distribution of noise exposure in Berlin. UMID Special issue II Environmental justice, 25–26.
- Landrigan P, Fuller R, Acosta N, Adeyi O, Arnold R, Basu N, Baldé A, Bertollini R, Bose-O'Reilly S, Boufford J, Breysse P, Chiles T, Mahidol C, Coll-Seck A, Cropper M, Fobil J, Fuster V, Greenstone M, Haines A, Hanrahan D, Hunter D, Khare M, Krupnick A, Lanphear B, Lohani B, Martin K, Mathiasen K, McTeer M, Murray C, Ndahimananjara J, Perera F, Potočnik J, Preker A, Ramesh J, Rockström J, Salinas C, Samson L, Sandilya K, Sly P, Smith K, Steiner A, Stewart R, Suk W, van Schayck O, Yadama G, Yumkella K, Zhong M, (2017). The Lancet Commission on pollution and health, 391(10119).
- Laußmann, D., Haftenberger, M., Lampert, T., and Scheidt-Nave, C. (2013). Soziale Ungleichheit von Lärmbelästigung und Straßenverkehrsbelastung: Ergebnisse der Studie zur Gesundheit Erwachsener in

Deutschland (DEGS1). Bundesgesundheitsblatt - Gesundheitsforschung - Gesundheitsschutz 56, 822–831.

- Le Boennec R. and Salladarré, F. (2017). The impact of air pollution and noise on the real estate market. The case of the 2013 European Green Capital: Nantes, France. Ecological Economics, 138, 82–89.
- Lejeune Z., Xhignesse G., Kryvobokov M., Teller J. (2016). Housing quality as environmental inequality: the case of Wallonia, Belgium. Journal of Housing and the Built Environment, 31(3), 495-512.
- Lercher P., de Kluizenaar Y. and Aasvang G-M. (2017). Special Issue "WHO Noise and Health Evidence Reviews", *International Journal of Environmental Research and Public Health* (ISSN 1660-4601), http://www.mdpi.com/journal/ijerph/special_issues/WHO_reviews [Accessed 15 March 2018].
- Lercher P., Pfeiffer C., Dekoninck L. and Botteldooren D. (2005). Traffic noise exposure, education and annoyance: Longitudinal experience from crosssectional surveys over time (1989-2004). (Budapest, Hungary), pp. 1795–1799.
- Liu Y., Huang L., Kaloudis A., Støre-Valen M. (2017). Does urbanization lead to less energy use on road transport? Evidence from municipalities in Norway, Transportation Research Part D: Transport and Environment, 57, 363-377.
- Liu, F. (2001). Environmental justice analysis: theories, methods, and practice (Boca Raton: Lewis Publishers).
- López-Aparicio S., Vogt M., Schneider P., Kahila-Tani M., Broberg A. (2017). Public participation GIS for improving wood burning emissions from residential heating and urban environmental management. Journal of Environmental Management 191, 179-188.
- London Assembly, Environment Committee (2015). Driving Away from diesel. Reducing air pollution from diesel vehicles. Retrieved from: https://www.london.gov.uk/sites/default/files/Driving%20Away%20from%20Diesel%20final%20report.pdf [last access 15/3/2018]
- Maga M., Janik M.K., Wachsmann A., Chrząstek-Janik O., Koziej M., Bajkowski M., Maga P., Tyrak K., Wójcik K., Gregorczyk-Maga I., Niżankowski R.,(2017). Influence of air pollution on exhaled carbon monoxide levels in smokers and non-smokers. A prospective cross-sectional study, Environmental Research, 152, 496-502.
- Maheswaran R., Pearson T., Beevers S.D., Campbell M.J., Wolfe C.D. (2016) Air pollution and subtypes, severity and vulnerability to ischemic stroke-a population based case-crossover study PLoS ONE.
- Marmot, M., and Wilkinson, R.G. (2006). Social determinants of health (Oxford: Oxford University Press.).
- Matejicek L. (2016). Spatial analysis of air pollution from road transport within urban areas and its relation to health risks. Air Pollution: Management Strategies, Environmental Impact and Health Risks, 17-40.
- Matthaios V.N., Triantafyllou A.G., Koutrakis P. (2017). PM_{10} episodes in Greece: Local sources versus long-range transport—observations and model simulations. Journal of the Air and Waste Management Association, 67(1), 105-126.
- Mediema and Vos, 1998. Exposure-response relationships for transportation noise. The Journal of the Acoustical Society of America. 1998 Dec;104(6):3432-45.
- Megido L., Negral L., Castrillón L., Fernández-Nava Y., Suárez-Peña B., Marañón E. (2017). Impact of secondary inorganic aerosol and road traffic at a suburban air quality monitoring station, Journal of Environmental Management, 189, 36-45.

- Meldrum K., Guo C., Marczylo E.L., Gant T.W., Smith R., Leonard M.O. (2017). Mechanistic insight into the impact of nanomaterials on asthma and allergic airway disease. Particle and Fibre Toxicology, 14(1), 45.
- Merklinger-Gruchala A., Jasienska G., Kapiszewska M. (2017). Parity Conditions the Risk for Low Birth Weight after Maternal Exposure to Air Pollution. Biodemography and Social Biology, 63(1), 71-86.
- Mesjasz-Lech A. (2016). Urban Air Pollution Challenge for Green Logistics, Transportation Research Procedia, 16, 355-365.
- Milojevic A., Niedzwiedz C.L., Pearce J., Milner J., MacKenzie I.A., Doherty R.M., Wilkinson P., (2017). Socioeconomic and urban-rural differentials in exposure to air pollution and mortality burden in England, Environmental Health: A Global Access Science Source, 16(1), 104.
- Miranda A.I., Ferreira J., Silveira C., Relvas H., Duque L., Roebeling P., Lopes M., Costa S., Monteiro A., Gama C., Sá E., Borrego C., Teixeira J.P. (2016). A cost-efficiency and health benefit approach to improve urban air quality. Science of the Total Environment, 569-570, 342-351.
- Mitchell, G., & Dorling, D. (2003). An environmental justice analysis of British air quality. Environment and Planning A, 35(5), 909–929.
- Mitchell, J.T., Thomas, D.S.K., and Cutter, S.L. (1999). Dumping in Dixie Revisited: The Evolution of Environmental Injustices in South Carolina. Soc. Sci. Q. 80, 229–243.
- Mitchell, Norman and Mullin, (2015).Who benefits from environmental policy? An environmental justice analysis of air quality change in Britain, 2001-2011.
- Morel, J., Marquis-Favre, C., and Gille, L.-A. (2016). Noise annoyance assessment of various urban road vehicle pass-by noises in isolation and combined with industrial noise: A laboratory study. Appl. Acoust. 101, 47–57.
- Morelli X., Rieux C., Cyrys J., Forsberg B., Slama R. (2016). Air pollution, health and social deprivation: A fine-scale risk assessment. Environmental Research, 147, 59-70.
- Moreno-Jiménez A., Cañada-Torrecilla R., Vidal-Domínguez M.J., Palacios-García A., Martínez-Suárez P. (2016). Assessing environmental justice through potential exposure to air pollution: A socio-spatial analysis in Madrid and Barcelona, Spain. Geoforum, 69, 117-131.
- Morrens B., Bruckers L., Den Hond E., Nelen V., G. Schoeters, W. Baeyens, N. Van Larebeke, H. Keune, M. Bilau, I. Loots (2012). Social distribution of internal exposure to environmental pollution in Flemish adolescent, Int J Hyg Environ Health. 2012 Jul;215(4):474-81.
- Most, M.T., Sengupta, R., and Burgener, M.A. (2004). Spatial Scale and Population Assignment Choices in Environmental Justice Analyses. Prof. Geogr. 56, 574–586.
- Mueller N, Rojas-Rueda D, Salmon M, Martinez D, Ambros A, Brand C, De Nazelle A, Dons E, Gaupp-Berghausen M, Gerike R, Götschi T, Iacorossi F, Panis L, Kahlmeier S, Raser E, Nieuwenhuijsen M (2018). Health impact assessment of cycling network expansions in European cities. Preventative Medicine In Press, Accepted Manuscript.
- Munford L.A. (2017). The impact of congestion charging on social capital. Transportation Research Part A: Policy and Practice, 97, 192-208.
- Munker S., Kilo S., Röß C., Jeitner P., Schierl R., Göen T., Drexler H. (2016). Exposure of the German general population to platinum and rhodium – Urinary levels and determining factors. International Journal of Hygiene and Environmental Health, 219(8), 801-810.
- Münzel T., Herzog J., Schmidt F.P., Sørensen M. (2017). Environmental stressors and cardiovascular disease: The evidence is growing. European Heart Journal, 38(29), 2297-2299.
- Muzet, A., Tinguely, G., Berengier, M., Coignard, F., Evrard, A.S., Faburel, G., Lelong, J., Lepoutre, P., Mietlicki, F., Nolli, M., Et Al. (2013). Evaluation des impacts sanitaires extra-auditifs du bruit environnemental : saisine 2009-sa-0333 : avis de l'anses : rapport d'expertise collective. In Evaluation

des impacts sanitaires extra-auditifs du bruit environnemental : saisine 2009-sa-0333 : avis de l'anses : rapport d'expertise collective, (Agence Nationale De Securite Sanitaire - Anses), P. 313.

- Nedellec V. and Rabl A., (2016). Costs of Health Damage from Atmospheric Emissions of Toxic Metals: Part 1—Methods and Results, Risk Analysis, 36(11), 2081-2095.
- Nieuwenhuijsen M.J. (2016). Urban and transport planning, environmental exposures and health-new concepts, methods and tools to improve health in cities. Environmental Health: A Global Access Science Source 15, 38.
- Nieuwenhuijsen M.J., Khreis H. (2016). Car free cities: Pathway to healthy urban living. Environment International 94, 251-262.
- Nieuwenhuijsen M.J., Khreis H., Verlinghieri E., Mueller N., Rojas-Rueda D. (2017). Participatory quantitative health impact assessment of urban and transport planning in cities: A review and research needs. Environment International 103, 61-72.
- Nieuwenhuijsen, Ristovska and Dadvand, 2017. WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Adverse Birth Outcomes. Int. J. Environ. Res. Public Health 2017, 14(10), 1252.
- O'Neill, M.S., Jerrett, M., Kawachi, I., Levy, J.I., Cohen, A.J., Gouveia, N., Wilkinson, P., Fletcher, T., Cifuentes, L., Schwartz, J., et al. (2003). Health, wealth, and air pollution: advancing theory and methods. Environ. Health Perspect. 111, 1861–1870.
- OECD (2016). Health at a Glance - State of Health in the EU Cycle.
- OECD (2017). Understanding the socio-economic divide in Europe, OECD, Paris France.
- Oliveira M., Slezakova K., Madureira J., de Oliveira Fernandes E., Delerue-Matos C., Morais S., do Carmo Pereira M. (2017). Polycyclic aromatic hydrocarbons in primary school environments: Levels and potential risks Science of the Total Environment, 575, 1156-1167.
- Olsen J.R., Mitchell R., Mutrie N., Foley L., Ogilvie D. (2017). Population levels of, and inequalities in, active travel: A national, cross-sectional study of adults in Scotland. Preventive Medicine Reports, 8, 129-134.
- Orru K., Orru H., Maasikmets M., Hendrikson R., Ainsaar M. (2016). Well-being and environmental quality: Does pollution affect life satisfaction? Quality of Life Research, 25(3), 699-705.
- Oudin A., Bråbäck L., Åström D.O., Forsberg B. (2017) Air pollution and dispensed medications for asthma, and possible effect modifiers related to mental health and socio-economy: A longitudinal cohort study of Swedish children and adolescents. International Journal of Environmental Research and Public Health, 14(11), 1392.
- Oudin A., Forsberg B., Adolfsson A.N., Lind N., Modig L., Nordin M., Nordin S., Adolfsson R., Nilsson L.-G. (2016a). Traffic-related air pollution and dementia incidence in Northern Sweden: A longitudinal study. Environmental Health Perspectives, 124(3), 306-312.
- Oudin A., Brabäck L., Aström D.O., Strömgren M., Forsberg B. (2016b). Association between neighbourhood air pollution concentrations and dispensed medication for psychiatric disorders in a large longitudinal cohort of Swedish children and adolescents. BMJ Open, 6(6), e010004.
- Paavola J. (2017) Health impacts of climate change and health and social inequalities in the UK. Environmental Health: A Global Access Science Source, 16, 113.
- Padilla C.M., Kihal-Talantikit W., Vieira V.M., Deguen S. (2016a). City-specific spatiotemporal infant and neonatal mortality clusters: Links with socioeconomic and air pollution spatial patterns in France. International Journal of Environmental Research and Public Health, 13(6), 1-21.
- Padilla C.M., Kihal-Talantikit W., Perez S., Deguen S. (2016b). Use of geographic indicators of healthcare, environment and socioeconomic factors to characterize environmental health disparities. Environmental Health: A Global Access Science Source, 15(1), 79.

- Papaefthimiou S., Maragkogianni A., Andriosopoulos K. (2016) Evaluation of cruise ships emissions in the Mediterranean basin: The case of Greek ports. International Journal of Sustainable Transportation, 10(10), 985-994.
- Pasquier A., André M. (2017). Considering criteria related to spatial variabilities for the assessment of air pollution from traffic, Transportation Research Procedia, 25, 3358-3373.
- Pellow, D.N., Weinberg, A., and Schnaiberg, A. (2001). The Environmental Justice Movement: Equitable Allocation of the Costs and Benefits of Environmental Management Outcomes. Soc. Justice Res. 14, 423–439.
- Perez-Prada F., Monzon A. (2017). Ex-post environmental and traffic assessment of a speed reduction strategy in Madrid's inner ring-road. Journal of Transport Geography 58 256 268.
- Poortinga, W., Dunstan, F.D., and Fone, D.L. (2008). Neighbourhood deprivation and self-rated health: The role of perceptions of the neighbourhood and of housing problems. Health Place 14, 562–575.
- Porta D., Narduzzi S., Badaloni C., Bucci S., Cesaroni G., Colelli V., Davoli M., Sunyer J., Zirro E., Schwartz J., Forastiere F. (2016). Air pollution and cognitive development at age 7 in a prospective Italian birth cohort. Epidemiology, 27(2), 228-236.
- Prata J.C., (2018). Airborne microplastics: Consequences to human health?, Environmental Pollution, 234, 115-126.
- QUADMAP-Quiet Urban Areas. Life Project. http://www.quadmap.eu/welcome/pilot-areas/
- Rancière F., Bougas N., Viola M., Momas I. (2017). Early exposure to traffic-related air pollution, respiratory symptoms at 4 years of age, and potential effect modification by parental allergy, stressful family events, and sex: A prospective follow-up study of the Paris birth cohort. Environmental Health Perspectives, 125(4), 737-745.
- Recio A., Linares C., Banegas J.R., Díaz J. (2016). The short-term association of road traffic noise with cardiovascular, respiratory, and diabetes-related mortality. Environmental Research 150, 383-390.
- Riedel N., Loerbroks A., Bolte G., Li J. (2017a). Do perceived job insecurity and annoyance due to air and noise pollution predict incident self-rated poor health? A prospective analysis of independent and joint associations using a German national representative cohort study. BMJ Open, 7, e012815.
- Riedel, N., van Kamp, I., Köckler, H., Scheiner, J., Loerbroks, A., Claßen, T., and Bolte, G. (2017b). Cognitive-Motivational Determinants of Residents' Civic Engagement and Health (Inequities) in the Context of Noise Action Planning: A Conceptual Model. Int. J. Environ. Res. Public. Health 14.
- Riley B. (2017). The state of the art of living walls: Lessons learned. Building and Environment 114, 219-232.
- RIVM (2011). Stamina model description. Available: http://www.rivm.nl/dsresource?objectid=ea993381-0369-41d8-a3fd-5fc7fa652c57&type=org&disposition=inline
- Russell-Jones R. (2016). Dirty diesel: Cities and citizens choke while the government looks the other way. BMJ (Online) 355, i6726.
- Russell-Jones R. (2017). Air pollution in the UK: Better ways to solve the problem. BMJ (Online), 357, j2713.
- Sacks J.D., Stanek L.W., Luben T.J., Johns D.O., Buckley B.J., Brown J.S., Ross M. (2011). Particulate Matter-Induced Health Effects: Who Is Susceptible? Environ Health Perspect 2011; 119 (4):446-54.
- Salmond J.A., Tadaki M., Vardoulakis S., Arbuthnott K., Coutts A., Demuzere M., Dirks K.N., Heaviside C., Lim S., MacIntyre H., McInnes R.N., Wheeler B.W. (2016). Health and climate related ecosystem

services provided by street trees in the urban environment. Environmental Health: A Global Access Science Source 15-36.

- Sanidas E., Papadopoulos D.P., Grassos H., Velliou M., Tsioufis K., Barbetseas J., Papademetriou V. (2017). Air pollution and arterial hypertension. A new risk factor is in the air. Journal of the American Society of Hypertension, 11(11), 709-715.
- Sarigiannis D.A., Handakas E.J., Kermenidou M., Zarkadas I., Gotti A., Charisiadis P., Makris K., Manousakas M., Eleftheriadis K., Karakitsios S.P. (2017). Monitoring of air pollution levels related to Charilaos Trikoupis Bridge, Science of the Total Environment, 609:1451-1463.
- Saunders P.J., Middleton J.D., Rudge G. (2017). Environmental Public Health Tracking: A cost-effective system for characterizing the sources, distribution and public health impacts of environmental hazards. Journal of Public Health (United Kingdom), 39(3), 506-513.
- Schade, M. (2014). Umwelt, Soziale Lage und Gesundheit bei Kindern in Frankfurt am Main. Universität Bielefeld.
- Schipper C.A., Vreugdenhil H., de Jong M.P.C. (2017). A sustainability assessment of ports and port-city plans: Comparing ambitions with achievements. Transportation Research Part D: Transport and Environment, 57, 84-111.
- Science for Environment Policy (2016) *Links between noise and air pollution and socioeconomic status*. In-depth Report 13 produced for the European Commission, DG Environment by the Science Communication Unit, UWE, Bristol. Available at: http://ec.europa.eu/science-environment-policy
- Seidler, A., Wagner, M., Schubert, M., Dröge, P., Römer, K., Pons-Kühnemann, J., Swart, E., Zeeb, H., and Hegewald, J. (2016). Aircraft, road and railway traffic noise as risk factors for heart failure and hypertensive heart disease—A case-control study based on secondary data. Int. J. Hyg. Environ. Health 219, 749–758.
- Shrestha R., Flacke J., Martinez J., Van Maarseveen M. (2016). Environmental health related socio-spatial inequalities: Identifying “hotspots” of environmental burdens and social vulnerability. International Journal of Environmental Research and Public Health 13 7 691.
- Siedl, S. (2016). Socio-spatial distribution of road traffic noise in Vienna, Austria. University of Natural Resources and Life Sciences.
- Simcock N., Mullen C. (2016). Energy demand for everyday mobility and domestic life: Exploring the justice implications. Energy Research and Social Science, 18, 1-6.
- Šlachtová H., Jiřík V., Tomášek I., Tomášková H. (2016) Environmental and socioeconomic health inequalities: A review and an example of the industrial Ostrava region. Central European Journal of Public Health, 24, S26-S32.
- Śliwińska-Kowalska, M. and Zaborowski, K., (2017). WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Permanent Hearing Loss and Tinnitus. Int. J. Environ. Res. Public Health 2017, 14(10), 1139.
- Strak M., Janssen N., Beelen R., Schmitz O., Karssenberg D., Houthuijs D., van den Brink C., Dijst M., Brunekreef B., Hoek G. (2017). Associations between lifestyle and air pollution exposure: Potential for confounding in large administrative data cohorts. Environmental Research, 156, 364-373.
- Stroh E., A. Oudin A, Gustafsson S., P. Pilesjö, L. Harrie, U. Strömberg and K. Jakobsson (2005). Are associations between socio-economic characteristics and exposure to air pollution a question of study area size? An example from Scania, Sweden.
- Sun Y., Mobasheri A., (2017). Utilizing crowdsourced data for studies of cycling and air pollution exposure: A case study using strava data, International Journal of Environmental Research and Public Health, 14(3), 274.

- Sun Y., Mobasheri A., Hu X., Wang W. (2017). Investigating impacts of environmental factors on the cycling behavior of bicycle-sharing user. Sustainability (Switzerland) 9 6 1060.
- Swiss Federal Office for the Environment (2012). Effects of air pollution on health. https://www.bafu.admin.ch/bafu/en/home/topics/air/info-specialists/effects-of-air-pollution/effects-of-air-pollution-on-health.html [Accessed 15 March 2018].
- Tainio M., Monsivais P., Jones N.R.V., Brand C., Woodcock J. (2017). Mortality, greenhouse gas emissions and consumer cost impacts of combined diet and physical activity scenarios: A health impact assessment study. BMJ Open, 7(2), e014199.
- Tajik, P., & Majdzadeh, R. (2014). Constructing Pragmatic Socioeconomic Status Assessment Tools to Address Health Equality Challenges. *International Journal of Preventive Medicine*, 5(1), 46–51.
- Temam S., Burte E., Adam M., Antó J.M., Basagaña X., Bousquet J., Carsin A.-E., Galobardes B., Keidel D., Künzli N., Le Moual N., Sanchez M., Sunyer J., Bono R., Brunekreef B., Heinrich J., de Hoogh K., Jarvis D., Marcon A., Modig L., Nadif R., Nieuwenhuijsen M., Pin I., Siroux V., Stempfelet M., Tsai M.-Y., Probst-Hensch N., Jacquemin B. (2017). Socioeconomic position and outdoor nitrogen dioxide (NO_2) exposure in Western Europe: A multi-city analysis. Environment International, 101, 117-124.
- ten Brink P., Mutafoglu K., Schweitzer J-P., Kettunen M., Twigger-Ross C., Baker J., Kuipers Y., Emonts M., Tyrväinen L., Hujala T., and Ojala A. (2016) The Health and Social Benefits of Nature and Biodiversity Protection. A report for the European Commission (ENV.B.3/ETU/2014/0039), Institute for European Environmental Policy, London/Brussels.
- Thiele, I., and Bolte, G. (2011). Bedeutung individueller sozialer Merkmale und Kontextfaktoren des Wohnumfelds für soziale Ungleichheit bei der Umweltqualität von Kindern -Impact of individual social characteristics and factors of the neighbourhood socioeconomic context on inequalities in children's environmental quality. UMID 59–62.
- Thornes J.E., Hickman A., Baker C., Cai X., Saborit J.M.D. (2017). Air quality in enclosed railway stations. Proceedings of the Institution of Civil Engineers: Transport, 170(2), 99-107.
- Tomei F., Ricci S., Giammichele G., Sacco C., Loreti B., Fidanza L., Ricci P., Scala B., Tomei G., Rosati M.V. (2017) Blood pressure in indoor and outdoor workers. Environmental Toxicology and Pharmacology, 55, 127-136.
- Tonne C., Halonen J.I., Beevers S.D., Dajnak D., Gulliver J., Kelly F.J., Wilkinson P., Anderson H.R. (2016). Long-term traffic air and noise pollution in relation to mortality and hospital readmission among myocardial infarction survivors. International Journal of Hygiene and Environmental Health 219, 1, 72-78.
- Trojanek, R., Tanas, J., Raslanas, S., and Banaitis, A. (2017). The Impact of Aircraft Noise on Housing Prices in Poznan. Sustainability 9.
- Tzivian L., Dlugaj M., Winkler A., Hennig F., Fuks K., Sugiri D., Schikowski T., Jakobs H., Erbel R., Jöckel K.-H., Moebus S., Hoffmann B., Weimar C., on behalf of the Heinz Nixdorf Recall Study Investigative Group (2016). Long-term air pollution and traffic noise exposures and cognitive function: A cross-sectional analysis of the Heinz Nixdorf Recall study. Journal of Toxicology and Environmental Health - Part A: Current Issues, 79(22-23), 1057-1069.
- Tzoulaki I., Elliott P., Kontis V., Ezzati M. (2016). Worldwide Exposures to Cardiovascular Risk Factors and Associated Health Effects: Current Knowledge and Data Gaps. Circulation, 133(23), 2314-2333.
- UK Government - Department for Communities and Local Government (2015). The English Index of Multiple Deprivation (IMD) 2015. Retrieved from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/464431/English_Index_of_Multiple_Deprivation_2015_-_Infographic.pdf [last access 26/01/2018].

- UMID, 2011. Special Issue II Environmental Justice.
- Urban Agenda for the EU. Pact of Amsterdam. (2016) Agreed at the Informal Meeting of EU Ministers Responsible for Urban Matters on 30 May 2016 in Amsterdam, The Netherlands.
- Urbancova K., Lankova D., Rossner P., Rossnerova A., Svecova V., Tomaniova M., Veleminsky M., Jr., Sram R.J., Hajslova J., Pulkrabova J.,(2017). Evaluation of 11 polycyclic aromatic hydrocarbon metabolites in urine of Czech mothers and newborns, Science of the Total Environment, 577, 212-219.
- Van Grinsven H.J.M., Tiktak A., Rougoor C.W. (2016). Evaluation of the Dutch implementation of the nitrates directive, the water framework directive and the national emission ceilings directive, NJAS - Wageningen Journal of Life Sciences, 78, 69-84.
- van Kempen et al, 2017. 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. 2018 Feb 22; 15(2):379.
- van Wee B., Ettema D. (2016). Travel behaviour and health: A conceptual model and research agenda. Journal of Transport and Health, 3(3), 240-248.
- Vanherle K. and Vergeer R. (2016).Data gathering and analysis to improve the understanding of 2nd hand car and LDV markets and implications for the cost effectiveness and social equity of LDV CO2 regulations, TML/ DG Climate Action.
- Vriens A., Nawrot T.S., Baeyens W., Den Hond E., Bruckers L., Covaci A., Croes K., De Craemer S., Govarts E., Lambrechts N., Loots I., Nelen V., Peusens M., De Henauw S., Schoeters G., Plusquin M. (2017). Neonatal exposure to environmental pollutants and placental mitochondrial DNA content: A multi-pollutant approach. Environment International, 106, 60-68.
- Westergaard N., Gehring U., Slama R., Pedersen M. (2017). Ambient air pollution and low birth weight - are some women more vulnerable than others? Environment International, 104, 146-154.
- Weyde, K.V., Krog, N.H., Oftedal, B., Magnus, P., Øverland, S., Stansfeld, S., Nieuwenhuijsen, M.J., Vrijheid, M., de Castro Pascual, M., and Aasvang, G.M. (2017). Road traffic noise and children's inattention. Environ. Health 16.
- WHO. Health Impact Assessment (HIA) – The determinants of health. Retrieved from: http://www.who.int/hia/evidence/doh/en/ [last access 26/01/2018].
- WHO (2009). Night noise guidelines for Europe. Copenhagen, Denmark.
- WHO (2012). Environmental Health inequalities in Europe. The WHO European Centre for Environment and Health, Bonn Office, WHO Regional Office for Europe.
- WHO (2013) Environmental Health Inequalities in Malta, Environmental Health Directorate/Department for Health Regulation.
- WHO (2016). Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks, http://apps.who.int/iris/bitstream/10665/204585/1/9789241565196_eng.pdf?ua=1 [Accessed 15 March 2018].
- WHO (2017). Preventing noncommunicable diseases (NCDs) by reducing environmental risk factors.
- Wilke, S. (2013). Soziale Verteilung von Umweltbelastungen.
- Wüstemann H., Kalisch D., Kolbe J. (2017). Access to urban green space and environmental inequalities in Germany. Landscape and Urban Planning, 164, 124-131.
- Zubero M.B., Eguiraun E., Aurrekoetxea J.J., Lertxundi A., Abad E., Parera J., Goñi-Irigoyen F., Ibarluzea J., (2017). Changes in serum dioxin and PCB levels in residents around a municipal waste incinerator in Bilbao, Spain, Environmental Research, 156, 738-746.

Appendix 1: Search terms

Air pollution

("air pollut*" OR "air toxics" OR "black carbon" OR "car emission*" OR "Carbon Dioxide" OR "Carbon monoxide" OR "CO2" OR "diesel emission*" OR "diesel fuel" OR "diesel fume*" OR "elemental carbon" OR "fine particle*" OR "nitrogen dioxide*" OR "nitrogen oxide*" OR "NO2" OR nox OR ozone OR particulate* OR "petrol emission*" OR "petrol fuel" OR "petrol fume*" OR "PM emission*" OR "PM2*" OR "PM5" OR "PM10" OR smog OR "SO2" OR "Sulphur dioxide" OR "ultrafine particle*" OR "Vehicle Emission*" OR "vehicle exhaust*" OR "vehicle fume*" OR "air particl*" OR "industrial emission*" OR "domestic emission*" OR "agricultural emission*")

AND

("Inhalation Exposure" OR "inhalation exposure" OR cardiovascular OR cvd OR disease OR health OR mortality OR threshold* OR stroke OR asthma OR "Blood pressure" OR "Body mass index" OR bmi OR cancer OR "Heart disease" OR "Physical health" OR "Mental health" OR diabetes OR "Heat vulnerability" OR "Health equity" OR "Health inequality" OR copd OR "Chronic Obstructive Pulmonary Disease" OR "premature deaths" OR epidemiology OR "Child* ill health" OR "Vulnerable population" OR "Vulnerable groups" OR "Elderly Ill health" OR elderly OR "Ill-health" OR "Hospital admissions for respiratory disease" OR "GP attendance" OR morbidity OR "Quality Adjusted Life Years" OR "Disability Adjusted Life Years" OR qaly OR daly OR exposure OR death* OR "child mortality" OR "health outcome" OR respiratory OR ischaemic OR "birth defects" OR "low birth weight" OR "congenital anomalies" OR "years of life lost" OR "lung function" OR cerebrovascular OR myocardial OR "heart attack" OR "oxidative stress" OR vascular OR "premature birth" OR "preterm birth" OR "pre-term birth")

AND

(deprivation OR imd OR "accumulation of risk factors" OR acorn OR "Breadline Britain Index" OR "British Household Panel Survey" OR bhps OR "Childhood poverty" OR "Children in Low Income Families" OR clif OR "Consensual Budget Standards" OR environmental AND (equity OR stressor) OR "EU Statistics on Income and Living Conditions" OR "EU-SILC" OR "European Community Household Panel Survey" OR echp OR "Family Resources Survey" OR frs OR "Groups at risk" OR "Households Below Average Income" OR "HBAI" OR "Income deprivation" OR "Index of Local Conditions" OR (index AND (jarman OR townsend OR carstairs) OR "Living standards" OR "Low-income individuals" OR matdep OR "Minimum budget standards" OR "Minimum Income for Healthy Living" OR mihl OR "Minimum Income Standards" OR "Office for National Statistics Area Classification" OR poor OR poverty OR "Poverty and Social Exclusion" OR pse OR scotdep OR (social AND (aspect* OR cohesion OR capital OR network OR class OR impacts OR inclusion OR inequality OR segregation OR status OR exclusion)) OR (socioeconomic AND (factors OR status)) OR "SES" OR "SuperProfiles" OR "Susceptible group*" OR underprivileged))

WITH PARAMETERS ADD:

AND (LIMIT-TO (AFFILCOUNTRY,"United Kingdom ") OR LIMIT-TO (AFFILCOUNTRY,"Germany ") OR LIMIT-TO (AFFILCOUNTRY,"Italy ") OR LIMIT-TO (AFFILCOUNTRY,"Spain ") OR LIMIT-TO (AFFILCOUNTRY,"France ") OR LIMIT-TO (AFFILCOUNTRY,"Netherlands ") OR LIMIT-TO (

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AFFILCOUNTRY,"Angola ") OR EXCLUDE (AFFILCOUNTRY,"Bahrain ") OR EXCLUDE (AFFILCOUNTRY,"Bermuda ") OR EXCLUDE (AFFILCOUNTRY,"Burkina Faso ") OR EXCLUDE (AFFILCOUNTRY,"Cambodia ") OR EXCLUDE (AFFILCOUNTRY,"Cameroon ") OR EXCLUDE (AFFILCOUNTRY,"Cuba ") OR EXCLUDE (AFFILCOUNTRY,"Laos ") OR EXCLUDE (AFFILCOUNTRY,"Madagascar ") OR EXCLUDE (AFFILCOUNTRY,"Maldives ") OR EXCLUDE (AFFILCOUNTRY,"Mozambique ") OR EXCLUDE (AFFILCOUNTRY,"Namibia ") OR EXCLUDE (AFFILCOUNTRY,"Senegal ") OR EXCLUDE (AFFILCOUNTRY,"Uruguay ") OR EXCLUDE (AFFILCOUNTRY,"Uzbekistan ") OR EXCLUDE (AFFILCOUNTRY,"Zambia ") OR EXCLUDE (AFFILCOUNTRY,"Zimbabwe ") OR EXCLUDE (AFFILCOUNTRY,"Afghanistan ") OR EXCLUDE (AFFILCOUNTRY,"Albania ") OR EXCLUDE (AFFILCOUNTRY,"Bahamas ") OR EXCLUDE (AFFILCOUNTRY,"Barbados ") OR EXCLUDE (AFFILCOUNTRY,"Bhutan ") OR EXCLUDE (AFFILCOUNTRY,"Bosnia and Herzegovina ") OR EXCLUDE (AFFILCOUNTRY,"Botswana ") OR EXCLUDE (AFFILCOUNTRY,"Cote d'Ivoire ") OR EXCLUDE (AFFILCOUNTRY,"Democratic Republic Congo ") OR EXCLUDE (AFFILCOUNTRY,"Dominican Republic ") OR EXCLUDE (AFFILCOUNTRY,"El Salvador ") OR EXCLUDE (AFFILCOUNTRY,"Faroe Islands ") OR EXCLUDE (AFFILCOUNTRY,"Fiji ") OR EXCLUDE (AFFILCOUNTRY,"French Guiana ") OR EXCLUDE (AFFILCOUNTRY,"Gabon ") OR EXCLUDE (AFFILCOUNTRY,"Georgia ") OR EXCLUDE (AFFILCOUNTRY,"Guatemala ") OR EXCLUDE (AFFILCOUNTRY,"Jamaica ") OR EXCLUDE (AFFILCOUNTRY,"Libyan Arab Jamahiriya ") OR EXCLUDE (AFFILCOUNTRY,"Mauritius ") OR EXCLUDE (AFFILCOUNTRY,"Montenegro ") OR EXCLUDE (AFFILCOUNTRY,"Nicaragua ") OR EXCLUDE (AFFILCOUNTRY,"Niger ") OR EXCLUDE (AFFILCOUNTRY,"Saint Kitts and Nevis ") OR EXCLUDE (AFFILCOUNTRY,"Seychelles ") OR EXCLUDE (AFFILCOUNTRY,"Suriname ")) AND (EXCLUDE (SUBJAREA,"BUSI ") OR EXCLUDE (SUBJAREA,"COMP ") OR EXCLUDE (SUBJAREA,"DENT ") OR EXCLUDE (SUBJAREA,"EART ") OR EXCLUDE (SUBJAREA,"PHYS ") OR EXCLUDE (SUBJAREA,"MATH ") OR EXCLUDE (SUBJAREA,"VETE ")) AND (LIMIT-TO (PUBYEAR,2018) OR LIMIT-TO (PUBYEAR,2017) OR LIMIT-TO (PUBYEAR,2016)) AND (LIMIT-TO (LANGUAGE,"English ") OR LIMIT-TO (LANGUAGE,"English ") OR EXCLUDE (LANGUAGE,"French ") OR EXCLUDE (LANGUAGE,"Spanish ") OR EXCLUDE (LANGUAGE,"Arabic ") OR EXCLUDE (LANGUAGE,"Croatian ") OR EXCLUDE (LANGUAGE,"Portuguese "))

8.1 Noise

((noise OR "noise pollution" OR "environmental noise" OR acoustics) AND (traffic OR "road traffic" OR "traffic impact assessment" OR "traffic control" OR rail* OR "rail impact assessment" OR aircraft OR airport OR industrial))

AND

("Inhalation Exposure" OR "inhalation exposure" OR cardiovascular OR cvd OR disease OR health OR mortality OR threshold* OR stroke OR asthma OR "Blood pressure" OR "Body mass index" OR bmi OR cancer OR "Heart disease" OR "Physical health" OR "Mental health" OR diabetes OR "Heat vulnerability" OR "Health equity" OR "Health inequality" OR copd OR "Chronic Obstructive Pulmonary Disease" OR "premature deaths" OR epidemiology OR "Child* ill health" OR "Vulnerable population" OR "Vulnerable groups" OR "Elderly Ill health" OR elderly OR "Ill-health" OR "Hospital admissions for respiratory disease" OR "GP attendance" OR morbidity OR "Quality Adjusted Life Years" OR "Disability Adjusted Life Years" OR qaly OR daly OR exposure OR death* OR "child mortality" OR "health outcome" OR respiratory OR ischaemic OR "birth defects" OR "low birth weight" OR "congenital anomalies" OR "years of life lost" OR "lung function" OR cerebrovascular OR myocardial OR "heart attack" OR "oxidative stress" OR vascular OR "premature birth" OR "preterm birth" OR "pre-term birth")

AND

(deprivation OR imd OR "accumulation of risk factors" OR acorn OR "Breadline Britain Index" OR "British Household Panel Survey" OR bhps OR "Childhood poverty" OR "Children in Low Income Families" OR clif OR "Consensual Budget Standards" OR environmental AND (equity OR stressor) OR "EU Statistics on Income and Living Conditions" OR "EU-SILC" OR "European Community Household Panel Survey" OR echp OR "Family Resources Survey" OR frs OR "Groups at risk" OR "Households Below Average Income" OR "HBAI" OR "Income deprivation" OR "Index of Local Conditions" OR (index AND (jarman OR townsend OR carstairs) OR "Living standards" OR "Low-income individuals" OR matdep OR "Minimum budget standards" OR "Minimum Income for Healthy Living" OR mihl OR "Minimum Income Standards" OR "Office for National Statistics Area Classification" OR poor OR poverty OR "Poverty and Social Exclusion" OR pse OR scotdep OR (social AND (aspect* OR cohesion OR capital OR network OR class OR impacts OR inclusion OR inequality OR segregation OR status OR exclusion)) OR (socioeconomic AND (factors OR status)) OR "SES" OR "SuperProfiles" OR "Susceptible group*" OR underprivileged))

WITH PARAMETERS ADD:
AND (LIMIT-TO (PUBYEAR,2018) OR LIMIT-TO (PUBYEAR,2017) OR LIMIT-TO (PUBYEAR,2016)) AND (EXCLUDE (SUBJAREA,"BUSI") OR EXCLUDE (SUBJAREA,"COMP") OR EXCLUDE (SUBJAREA,"EART") OR EXCLUDE (SUBJAREA,"PHYS") OR EXCLUDE (SUBJAREA,"MATH") OR EXCLUDE (SUBJAREA,"VETE")) AND (LIMIT-TO (AFFILCOUNTRY,"United Kingdom") OR LIMIT-TO (AFFILCOUNTRY,"Germany") OR LIMIT-TO (AFFILCOUNTRY,"Spain") OR LIMIT-TO (AFFILCOUNTRY,"Italy") OR LIMIT-TO (AFFILCOUNTRY,"France") OR LIMIT-TO (AFFILCOUNTRY,"Netherlands") OR LIMIT-TO (AFFILCOUNTRY,"Sweden") OR LIMIT-TO (AFFILCOUNTRY,"Denmark") OR LIMIT-TO (AFFILCOUNTRY,"Belgium") OR LIMIT-TO (AFFILCOUNTRY,"Norway") OR LIMIT-TO (AFFILCOUNTRY,"Portugal") OR LIMIT-TO (AFFILCOUNTRY,"Finland") OR LIMIT-TO (AFFILCOUNTRY,"Poland") OR LIMIT-TO (AFFILCOUNTRY,"Austria") OR LIMIT-TO (AFFILCOUNTRY,"Greece") OR LIMIT-TO (AFFILCOUNTRY,"Ireland") OR LIMIT-TO (AFFILCOUNTRY,"Bulgaria") OR LIMIT-TO (AFFILCOUNTRY,"Lithuania") OR LIMIT-TO (AFFILCOUNTRY,"Slovakia") OR LIMIT-TO (AFFILCOUNTRY,"Czech Republic") OR LIMIT-TO (AFFILCOUNTRY,"Luxembourg") OR LIMIT-TO (AFFILCOUNTRY,"Romania") OR LIMIT-TO (AFFILCOUNTRY,"Estonia") OR LIMIT-TO (AFFILCOUNTRY,"Iceland") OR LIMIT-TO (AFFILCOUNTRY,"Slovenia") OR LIMIT-TO (AFFILCOUNTRY,"Croatia") OR LIMIT-TO (AFFILCOUNTRY,"Latvia") OR LIMIT-TO (AFFILCOUNTRY,"Malta")) AND (LIMIT-TO (LANGUAGE,"English"))

Appendix 2: List of documents analysed in the review of environmental policy (section 2.2)

- Commission staff working document: **key European action supporting the 2030 Agenda and the Sustainable Development Goals,** Strasbourg 22/11/2016 SWF(2016)390 final
- Communication from the Commission **Europe 2020 - A strategy for smart, sustainable and inclusive growth**, Brussels, 3/3/2010 COM(2010)2020 final
- Communication from the Commission to the Council and the European Parliament - **Thematic Strategy on air pollution** {SEC(2005) 1132} {SEC(2005) 1133} COM(2005)446 final
- Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions - **Thematic Strategy for Soil Protection**, Brussels 22/9/2006 COM(2006)231 final
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - **Annex Guidance to Member States: Suggested Actions on Better environmental implementation** to the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - **A European Strategy for Plastics in a Circular Economy**, COM(2018)28final
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - **The EU Environmental Implementation Review: Common challenges and how to combine efforts to deliver better results**, Brussels 3/2/2017 COM(2017)63 final
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - **Roadmap to a Resource Efficient Europe**, Brussels 20/9/2011, COM(2011)571 final
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - **Public Procurement for a better environment**, Brussels, 16/7/2008 COM(2008)400 final
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions on **the sustainable consumption and production and sustainable industrial policy action plan**. Brussels 16/7/2008. COM(2008)397 final
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - **Next steps for a sustainable European future. European action for sustainability**. Strasbourg 22/11/2016 COM(2016)739 final
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - **Green Infrastructure (GI) - Enhancing Europe's Natural Capital**. Brussels 6.5.2003. COM(2013)249 final
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - an **EU Strategy on adaptation to climate change**. Brussels 16/4/2013. COM(2013)216 final

- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – **A European Strategy for Low-Emission Mobility**. Brussels 20/7/2016 COM(2016)501 final
- Communication from the Commission to the European Parliament, the Council, the European economic and Social Committee and the Committee of the Regions – **Energy Roadmap 2050**. Brussels, 15/12/2011 COM(2011) 885 final
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions **- A Roadmap for moving to a competitive low carbon economy in 2050**. Brussels 8/3/2011. COM(2011) 112 final
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – **A policy framework for climate and energy in the period from 2020 to 2030**. Brussels 3/2/2014; COM(2014) 15 final.
- Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions**: A Global Partnership for Poverty Eradication and Sustainable Development after 2015**
- Council of the European Union**, A new global partnership for poverty eradication and sustainable development after 2015** – Council Conclusions, Brussels 26/05/2015, 9241/15
- 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'**. Official Journal of the European Union L 354/175, 28/12/2013
- Declaration of the Sixth Ministerial Conference of Environment and Health. **Better Health. Better Environment. Sustainable Choices.** Ostrava, Czech Republic 15 June 2017 EURO/Ostrava2017/6
- Directive (EU) 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the **limitation of emissions of certain pollutants into the air from medium combustion plants**
- Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on **the reduction of national emissions of certain atmospheric pollutants**, amending Directive 2003/35/EC and repealing Directive 2001/81/EC L 344/4 17/12/2016
- Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 **establishing a framework for Community action in the field of water policy**
- Directive 2001/42/E of the European Parliament and of the Council of 27 June 2001 on the **assessment of the effects of certain plans and programmes on the environmen**t OJ L 197/30 21/7/2001`
- 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**
- Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on **ambient air quality and cleaner air for Europe** (OJ L 152, 11/6/2008, p.1). Amended by Commission Directive (EU) 2015/1480 of 28 August 2016 OJ L 226, 29/8/2015, p. 4
- Directive 2008/56/EC of the European Parliament and of the Council of June 2008 **establishing a framework for community action in the field of marine environmental policy** (Marine Strategy Framework Directive), OJ L164/19, Brussels 25/6/2008
- Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on **waste and repealing certain Directives**. Brussels 22/11/2008 OJ L312/3
- Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the **conservation of wild birds**
- Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the **assessment of the effects of certain public and private projects on the environment** OJ L 26/1

- Directive 92/43/EEC of 21 May 1992 on the **conservation of natural habitats and of wild fauna and flora**
- Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the **Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)** establishing a European Chemical Agency… OJ L 396 20/12/2006 p.1
- **Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system**. Brussels 28/3/2011 COM(2011)144 final
- Sixth Ministerial Conference on Environment and Health. **Annex 1. Compendium of possible actions to advance the implementation of the Ostrava declaration**. Ostrava Czech Republic. 15 June 2017. EURO/Ostrava2017/7
- **Territorial Agenda of the European Union 2020 – Towards an Inclusive, Smart and Sustainable Europe of Diverse Regions.** Agreed at the Informal Ministerial Meeting of Ministers responsible for Spatial Planning and Territorial Development on 19th May 2011 Gödöllő, Hungary.
- United Nations – **Transforming our world: the 2030 Agenda for Sustainable Development** – Resolution adopted by the General Assembly on 25 September 2015
- **Urban Agenda for the EU – Pact of Amsterdam.** Agreed at the Informal Meeting of EU Ministers Responsible for
- **Urban Matters on 30 May 2016 in Amsterdam, The Netherlands**
- WHO/Regional Office for Europe. **Health 2020 – A European policy framework and strategy for the 21st century**

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