European Commission

Science for Environment Policy

IN-DEPTH REPORT 13

Links between noise and air pollution and socioeconomic status

September 2016

Environment

Science for Environment Policy

Links between noise and air pollution and socioeconomic status

Contents

The contents and views included in Science for Environment Policy are based on independent research and do not necessarily reflect the position of the European Commission.

This In-depth Report is written and edited by the Science Communication Unit, University of the West of England (UWE), Bristol

Email: sfep.editorial@uwe.ac.uk

To cite this publication:

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

Acknowledgements

For their contributions to this report, we would like to thank the scientific advisor Niamh Shortt at the Centre for Research on Environment, Society and Health, University of Edinburgh and Jo Barnes at the Air Qualiity Management Resource Centre , University of the West of England.

Final responsibility for the content and accuracy of the report, however, lies solely with Science for Environment Policy.

ISBN 978-92-79-45734-0
ISSN 2363-2798
DOI 10.2779/200217

Image on facing page: Airbus A340 Virgin Atlantic lands at Heathrow. Heathrow Airport, London, England - September 9, 2012: Virgin Atlantic Airbus A340 approaches Heathrow Airport flying low over homes near the runway. ©Backyard Production @iStock, 2012.

Image on page 9 and 15: with thanks to David Courey @ Noun Project.

Figure 3, page 16: amended March 2017.

About Science for Environment Policy

Science for Environment Policy is a free news and information service published by the European Commission's Directorate-General Environment, which provides the latest environmental policy-relevant research findings.

In-depth Reports are a feature of the service, introduced in 2012, which take a comprehensive look at the latest science for key policy topics. In addition to In-depth Reports, Science for Environment Policy also publishes a weekly **News Alert** which is delivered by email to subscribers and provides accessible summaries of key scientific studies.

http://ec.europa.eu/science-environment-policy

Keep up-to-date

Subscribe to Science for Environment Policy's weekly **News Alert** by emailing:
sfep@uwe.ac.uk
Or **sign up online** at:
http://ec.europa.eu/science-environment-policy

Executive Summary

Links between noise and air pollution and socioeconomic status

Air pollution and noise pollution have a negative impact on all of society — but some groups are more affected than others. Lower socioeconomic status is generally associated with poorer health, and both air and noise pollution contribute to a wide range of other factors influencing human health. But do these health inequalities arise because of increased exposure to pollution, increased sensitivity to exposure, increased vulnerabilities, or some combination? This In-depth Report presents evidence on whether people in deprived areas are more affected by air and noise pollution — and suffer greater consequences — than wealthier populations.

Air and noise pollution have many of the same sources, such as heavy industry, aircraft, railways and road vehicles. Research suggests that the social cost of noise and air pollution in the EU — including death and disease — could be nearly €1 trillion. For comparison, the social cost of alcohol in the EU has been estimated to be €50-120 billion and smoking at €544 billion.

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. Furthermore, these same people may be more impacted by pollution's damaging effects than more advantaged groups of society.

Executive Summary

This In-depth Report from Science for Environment Policy explores scientific research into the relationship between air and noise pollution, socioeconomic factors and health. In particular, it considers whether some socioeconomic groups suffer worse health as a result of greater exposure and/or vulnerability to air and noise pollution. Particular attention is paid to the situation in Europe, although the report draws on global experiences.

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), anxiety, depression 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 as a result 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 socioeconomic status 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. A number of studies show that polluted city centre locations are often favoured by affluent groups, for example.

Lower socioeconomic status is associated with poorer health in a more general sense. Numerous studies have shown increased health effects or deaths in deprived populations

City Pollution and Environmental Data Infographic © filo @iStock, 2015.

associated with noise and air pollution, compared with wealthier populations. Again, studies tend to be carried out in specific regions or cities, with a few exceptions 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 in a fairly linear fashion, 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.

From the evidence presented here, it looks likely that deprived populations living in areas that are exposed to high levels of pollution, or are exposed over a long duration, will assuredly 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.

This report highlights some of the methodological challenges faced by researchers in this field; an understanding of these issues can help policymakers, planners and organisations interpret and compare study results. For example, different studies define socioeconomic status in different ways. They also 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.

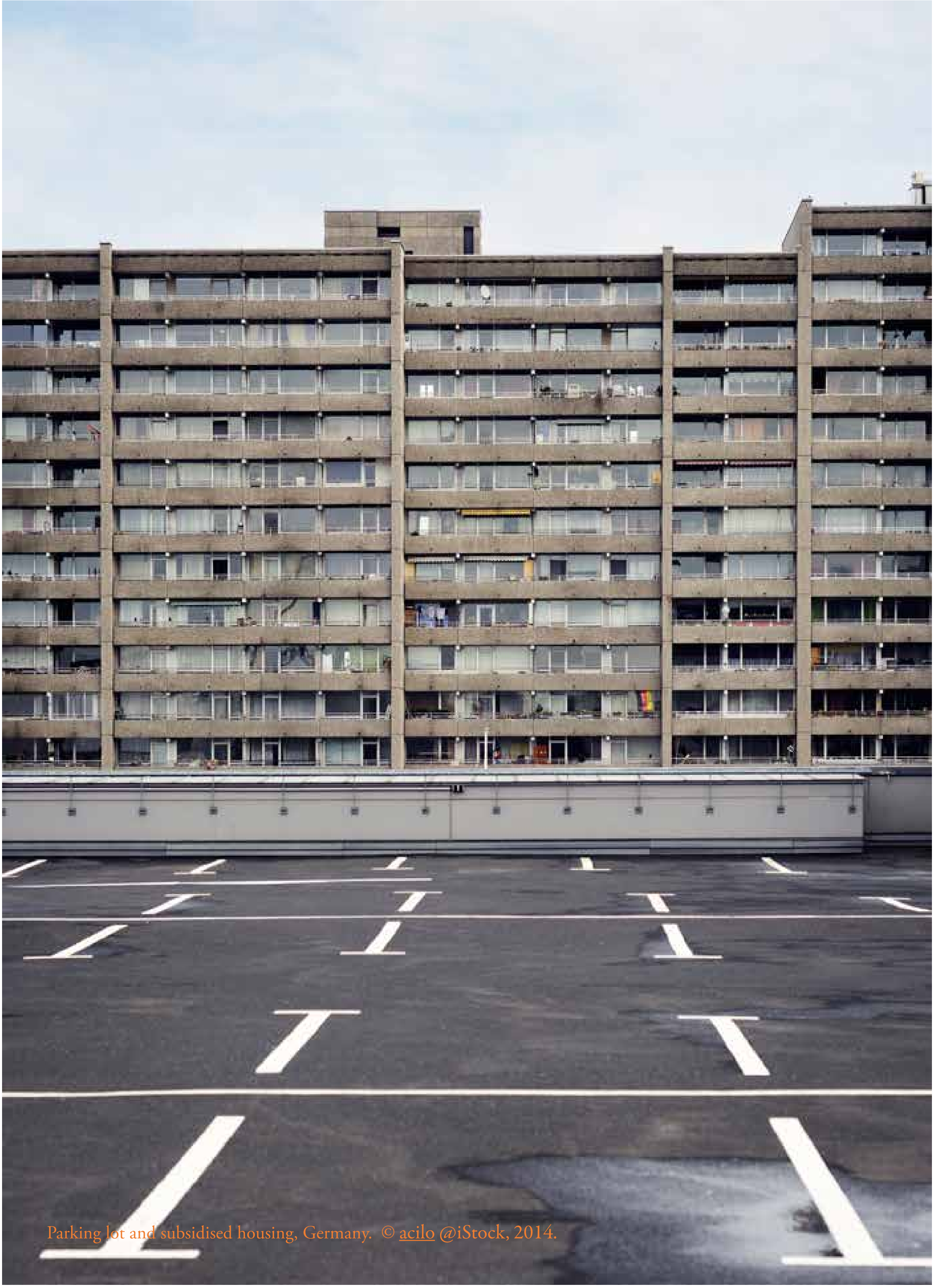
The existing evidence on this topic should be treated with some caution due to a lack of consistency in study methods. It is currently difficult to compare and contrast results between studies, or to draw wider conclusions about the role of socioeconomic status in exposure to noise and air pollution and resulting health impacts.

Further studies directly measuring both exposure and health impacts are needed to explore associations between socioeconomic status and noise and air pollution in Europe. Longitudinal studies — involving multiple rounds of data collection — are required to understand the long-term consequences of exposure to air and noise pollution. Also needed are studies investigating the effects of moving between areas with different socioeconomic characteristics and with different levels of exposure to pollution.

Despite these uncertainties, there is plenty of evidence to enable action; it is evident that reducing noise and air pollution will have a positive impact on health for all. In addition to universal measures, targeted measures designed to reduce exposure particularly in deprived populations will reduce the risk of the poorest in society suffering greater health consequences related to noise and air pollution.

Promoting and adopting more sustainable forms of transport could, for instance, reduce both noise and air pollution from traffic, whilst intelligent use of spatial planning tools and data could separate living and working areas from polluted areas. More stringent limits on both air and noise emissions, including combined emissions, would also reduce health impacts for everyone. Also, the evidence supports targeted measures to reduce the *vulnerability* of socioeconomically deprived populations to the health impacts of polluted environments, to ensure that they are not subjected to greater risks via lack of resources, greater sensitivity and greater exposure.

Policies which tackle a broader spectrum of socioeconomic and health inequalities could have co-benefits. For example, public campaigns to reduce smoking addiction would likely have a positive effect on a variety of health outcomes. Also, encouraging more active travel (walking and cycling) could reduce greenhouse gas emissions and reliance on non-renewable fuels, in addition to reducing inequalities in exposure to air and noise pollution.



Parking lot and subsidised housing, Germany. © acilo @iStock, 2014.

Introduction

The toll of air and noise pollution: who is most affected?

Air pollution and environmental noise present significant risks to our physical and mental health. Heart disease, respiratory disease and anxiety are just some of the conditions associated with either, or both, of these environmental burdens. In the World Health Organization (WHO) European region, nearly 600 000 premature deaths annually are linked to outdoor air pollution (WHO Regional Office for Europe, OECD, 2015). In addition, environmental noise causes at least 10 000 cases of premature death in Europe each year (EEA, 2014).

However, the risks from noise and air pollution are not evenly shared throughout society. Social inequalities affect where and how people live and it is often society's poorest who live and work in the lowest quality environments. This means that some socioeconomic groups may live in more polluted areas than other groups. More deprived socioeconomic groups are also more likely to have underlying health conditions that may make them more vulnerable to pollution's effects.

This In-depth Report explores scientific research into the relationship between socioeconomic factors, health, and air and noise pollution. In particular, it considers whether some socioeconomic groups suffer worse health as a result of greater exposure and/or vulnerability to air and noise pollution.

There are considerable difficulties in carrying out studies on this topic. The pathway from the source of the pollution to exposure, and from exposure to health impact, is complex. It is also difficult to predict the impact of specific levels of air or noise pollution or for an individual without detailed knowledge of that person's living situation and lifestyle. Difficulties also exist on the socioeconomic side; in particular a lack of 'stable' metrics for demonstrating social equality makes it difficult to draw conclusions across various metrics and studies.

Policy context

Air and noise pollution are regulated separately. In the EU, the Air Quality Directive (2008/50/EC)[1] has set targets for concentrations of various air pollutants to be met by 2010, or 2015 at the latest. Many EU Member States are not currently fulfilling their legal duties; to help, the Clean Air Policy Package[2] sets out a programme towards broad compliance by 2020, together with measures to achieve more ambitious health impact reductions by 2030 (the proposal for a revised National Emission Ceilings Directive, and the now-adopted Medium Combustion Plants Directive (EU) 2015/2193[3]).

The Environmental Noise Directive (2002/49/EC)[4] 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.

Dealing with health inequalities in relation to noise and air pollution depends not just on international and national level commitments, but also on local measures to reduce exposure and vulnerability among the most exposed people in society, irrespective of social status.

Measures may prioritise the most at-risk groups through targeted interventions to improve living conditions and pollution levels for these people. Spatial planning to identify priority areas, building design and protection and enhancement of quiet areas may also play a role (Harris and Pinoncély, 2014; Pope *et al.*, 2014). Meanwhile, action to tackle congestion and promote more sustainable forms of transport can have joint benefits — for all sectors of society — by helping to reduce both air and noise pollution, and their impacts on physical and mental health.

1. *http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0050&from=en*
2. *http://ec.europa.eu/environment/air/clean_air_policy.htm*
3. *http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32015L2193*
4. *http://ec.europa.eu/environment/noise/directive_en.htm*

Part 1: Noise and air pollution and socioeconomic status

Many different types of air and noise pollution can have many different effects on our health. Part 1 of this report introduces the problems of air pollution and noise pollution in a changing world. It considers these in relation to the socioeconomic factors that affect exposure and vulnerability to these pollutants.

1.1 Global trends

Urban populations

Air and noise pollution concentrate around cities, though are not exclusive to urban areas. At the beginning of the 20th century, less than 14% of the world's population lived in urban environments (PRB, 2015). Today, more than half live in a city. In industrialised nations, the number of urban dwellers is much higher (80%) (Grimm *et al.*, 2008), with Europe's urban population predicted to exceed 580 million across 48 nations by 2050 (United Nations, Department of Economic and Social Affairs, Population Division, 2014). Urban living brings people closer to jobs and allows industry and creativity to flourish, but it may be associated with a more stressful social environment and greater social inequalities. People living in cities also face an increased risk of chronic health disorders, and growing up in a city is linked to higher stress levels (Lederbogen *et al.*, 2011). It has been estimated that the risk of anxiety disorders is 21% higher and the risk of mood disorders 39% higher for those living in the urban environment.

Sources and levels of pollution

Historically, air pollution has increased alongside industrialisation and the development of more technically advanced transport systems. However, in Organisation for Economic Co-operation and Development (OECD)[5] countries (including a number of EU Member States) the trend is reversing as tighter emissions standards and limits come into force (OECD, 2014).

The main air pollutants that pose a risk to human health are nitrogen oxides (NOx), particulate matter (PM2.5 and PM10), tropospheric (ground-level) ozone (O3) and sulphur dioxide (SO2). Exposure to PM2.5 and PM10, for example, is associated with mortality from cardiovascular and respiratory diseases and from lung cancer, as well as respiratory and cardiovascular morbidity, such as aggravation of asthma, and respiratory symptoms (WHO, 2013a).

Figure 1: Contributions to EU-28 emissions from main source sectors (gigagrams (Gg)/year — 1 000 tonnes/year) of PM10, PM2.5, NOX (2003–2012) © European Environment Agency, Air Quality in Europe — 2014 report. EEA Report No. 5/2014.

5. http://www.oecd.org/about/membersandpartners/

Overall, commercial, institutional and household fuel-burning is the main source of primary (i.e. directly released) PM10 (43%) and PM2.5 (58%) in EU countries. This is followed by industry and then transport, which both emit less than half the total PM of fuel-burning (EEA, 2015a). However, secondary particles (i.e. those that are formed in the air through chemical reactions of gaseous pollutants), originating from agriculture, energy, transport or industry sectors, make up a significant proportion of total PM. Secondary particles are the largest relative contribution to PM in Europe, even in urban areas (Lelieveld *et al.*, 2015). Agriculture is also now the third most important source of primary PM10 emissions in the EU, after the 'commercial, institutional and household fuel combustion' and industry sectors. The energy sector accounts for the highest proportion (56%) of sulphur oxides (SOx) (EEA, 2015a).

Road transport, shipping and aviation are together responsible for more than half of all European NOx emissions in Europe (33 countries), with the energy sector contributing approximately half as much and industry and fuel-burning emitting smaller amounts again (EEA, 2015b). (Sectoral emissions of PM and NOx for 2003–2012 are shown in **Figure 1**). The same transport sectors emit smaller proportions of the other key pollutants, and are also a source of harmful noise emissions.

Cities remain air pollution hotspots, with driving habits largely determining daily and weekly patterns of pollution levels (Grimm *et al.*, 2008). In recent years, traffic restrictions have been imposed in some EU cities during high PM episodes (EEA, 2014b).

Meanwhile, noise pollution has also been increasing with industry and transport growth. However, in contrast with air pollution, noise pollution continues to increase in EU countries (WHO, 2011). Despite this increase, there are still no strict limits for community noise levels (Pope, 2015).[6]

> *Low-income populations tend to live in poor-quality buildings, with greater exposure to adverse environmental conditions, and less access to open space than those with higher incomes.*

6. *(Air quality standards, by comparison, have become increasingly stringent.) The WHO Regional Office for Europe is currently in the process of developing environmental noise guidelines which update its community noise guidelines of 1999. These will provide advice for its Member States on limiting the harmful effects of noise pollution (WHO Europe, 2015).*

1.2 Spatial scales of impacts

Health inequalities exist at both global and local levels. The urban environments in EU Member States can be safer and healthier places to live than in many lower-income countries. However, within any one European city there are those who are exposed to far greater risks from pollution compared with others living in the same city. These health inequalities can be a result of social inequalities.

Considering air quality at a regional level, O_3 concentrations are highest in southern EU countries, whilst northern Italy and Eastern Europe have the highest concentrations of PM10 (Pearce *et al.*, 2013). Low-income populations tend to live in poor-quality buildings, with greater exposure to adverse environmental conditions, and less access to open space than those with higher incomes.

A lack of financial capital and resources reduces their opportunities to move to areas with lower levels of pollution (Harris and Pinoncély 2014). This is true at both regional and neighbourhood levels within the EU.

Deciding at which scale (regional or neighbourhood areas, for example) to measure pollution and health impacts is a topic of debate for researchers in the field (Putrik *et al.*, 2014). Air pollution levels vary at the national, regional and even very local level. As an added complication, units of area are not standardised across all studies. For example, researchers may study areas that are based on historical or administrative borders, or they may even rely on participants' own perceptions of where the borders lie. These differing research approaches make interpreting and comparing results on health impacts more complicated, and it can be difficult to reach firm conclusions on the effects of living in more deprived or more polluted areas.

For this report, we identified a very limited number of studies which focus on how socioeconomic factors may lead to differences in exposure to noise and air pollution at the European or global levels. Most studies focus on socioeconomic differences at local and neighbourhood scales. This focus, of the research carried out so far, limits the drawing of firm conclusion about the chain of effects or causation between pollution levels, socioeconomic status and health implications. However, some indications can be understood from the more local-scale studies; the larger-scale questions would need to be answered with larger-scale research. Evidence from all studies is discussed in **section 3.2. Section 3.1** considers some of these methodological difficulties in more detail.

1.3 Types of noise and air pollution

Table 1 lists some of the most important anthropogenic sources of air and noise pollution along with types of emissions for air pollution. As shown, several sectors contribute to both air pollution and noise emissions. Although greenhouse gases (GHGs) are listed here to provide an overall picture, they do not form part of the main discussion of this report, as they have a more climatic-level impact on health than other emissions. NOx gases and PM tend to be the most widely researched pollutants, with PM associated with some of the most severe health effect (Lee *et al.*, 2014).

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

Table 1: Sources and types of air pollution and noise emissions

1.4 Types of health impact

An exhaustive review of the many different impacts of noise and air pollution is beyond the scope of this report, which focuses on socioeconomic influences. However, some background is necessary. **Table 2** provides a brief overview of the main impacts of noise and air pollution as indicated by research featured in this In-depth Report

Air and noise pollution can affect our physical and mental health, as well as behaviours that may have indirect effects on health. Noise can also have an impact on our productivity levels (in the workplace, for example), through cognitive effects. Simply stated, it is difficult to concentrate in noisy environments (Treasure, n.d.) or if you have not slept well due to excessive noise.

Details of impacts on cardiovascular health, mental health and sleep are expanded further in **Part 2** of this report. There are differences between the types of impacts caused by noise and the types of impacts caused by air pollution, as well as key overlaps. For example, although anxiety is

Sources categories	Key noise emitters	Key air emissions
Physiological / physical	• Heart disease • Hearing loss	• Heart disease • Respiratory disease • Asthma
Psychological / emotional	• Depression • Anxiety	• Anxiety
Behavioural	• Sleep disturbance • Annoyance • Aggression	• Physical activity levels
Cognitive	• Productivity levels • Learning disturbance	

Table 2: Main health impacts of noise and air pollution

more commonly linked with noise pollution, it has also been linked with PM (Power *et al.*, 2015), and studies on associations between noise and heart disease are becoming just as common as they are for air pollution.

1.4.1 Disentangling noise and air pollution's effects

Perhaps the most obvious reason for treating noise and air pollution as linked is that they often come from the same sources. Heavy industry, aircraft, railways and road vehicles (see **Table 1** in **1.3**) all contribute to both noise and air pollution emissions.

However, one problem with a joint focus is that it can be difficult to separate their similar impacts, certainly in the case of transport emissions. This is referred to as 'multi-causality' in epidemiological terms.

A UK report on the health effects of aircraft noise cited several studies where it was difficult to separate effects that were due to noise emissions from aircraft and those that were due to air pollution emissions (Civil Aviation Authority, 2014). One of those cited, Floud *et al.* (2013), looked at associations between aircraft and road traffic noise and heart disease across six European countries. This study found a potential link between exposure to both road traffic and aircraft noise and heart disease and stroke. The association between aircraft noise and health impacts was not affected by air pollution, but the researchers could not separate the effects of noise and air pollution (NO2) ffrom road traffic on health. A separate study on the impacts of aircraft noise carried out at Heathrow Airport, UK, also found a link between noise and heart disease even when the effects of PM and other air pollutants were considered (Hansell *et al.*, 2013).

According to a 2013 report of the European Network on Noise and Health (Lekaviciute *et al.*, 2013), although "disentangling the effects of noise and air pollution is a challenging task", it *is* possible to separate out their effects. The report estimates the correlation between traffic-related noise and traffic-related air pollution exposure at 0.3-0.6 (where a correlation of 1.0 indicates a perfect association). This range indicates that the two may be quite weakly or moderately associated, depending on the specific urban environment. The researchers therefore suggest that it is possible to determine, for instance, what proportion of heart disease cases may be attributed to air pollutant emissions from road vehicles and what proportion may be attributed to road traffic noise.

1.5 Spotlight on transport emissions

A large number of studies that consider socioeconomic differences focus on exposure to traffic pollution. Thus traffic pollution forms an important part of the discussion in this report.

Many studies have shown that living closer to main roads increases health risks for a wide range of conditions. These increases are seen in both deprived and privileged areas, but more deprived populations may be at greater risk. Both air and noise pollution from road traffic appear to lead to health effects. Road transport was named as the most concerning source of air pollution source by 100 experts who completed a WHO Europe 'Health Risks in Air Pollution' survey in 2013 (Henschel and Chan, 2013). Alongside the development of chronic diseases and increased risk of respiratory illness via exposure to traffic-related air pollution, the WHO has classed diesel exhaust as carcinogenic[7].

7. https://www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf

Transport-related pollution is subject to regulations, such as vehicle emissions controls and vehicle noise limits. The Euro 6 standard[8], introduced in 2014, is the current set of limits for air pollution emissions from cars and other light-duty road vehicles. It includes limits for CO, PM, NOx and hydrocarbons. New limits for vehicle noise have recently been adopted under Regulation 540/2014[9] on the sound level of motor vehicles. However, in some cases, real world pollution emissions have not reduced in line with the limit values (in particular for diesel emissions of NO2). Moreover, limits on individual vehicles — and other emissions sources — do not take into account a person's overall exposure to pollution from all sources.

Urban sprawl and inadequate spatial planning have created a situation in many cities where it is more convenient for people to drive than to use more sustainable forms of transport (Harris and Pinoncély, 2014). In established cities, public and industrial infrastructure has already created physical boundaries for noise and air pollution to some extent. However, it is possible to reduce the social inequalities that put the most deprived communities at the greatest risk from pollution by prioritising neighbourhoods for action (Pelletier, 2013).

1.6 Socioeconomic status, health and pollution

> "There is a social gradient in health — the lower a person's social position, the worse his or her health."
>
> Marmot *et al.* (2010)

There is now a significant body of evidence which shows that people in lower socioeconomic groups have a higher risk of various health problems. For instance, less educated groups were shown to be at higher risk of stroke, diseases of the nervous system, diabetes and arthritis in eight European national health surveys conducted in the 1990s (although more educated groups were at greater risk of allergy) (Dalstra *et al.*, 2005). This evidence base has been much strengthened in the past two decades.

The 'socioeconomic status-health gradient' is an important concept. It refers to this known link between socioeconomic status and health — that health tends to be better in people of high socioeconomic status and worse in those of low socioeconomic status. However, there are many factors which affect this health gradient; 'socioeconomic status' is just one possible influence.

It is often society's poorest who live and work in the lowest quality environments, areas that are experience the highest levels of pollution and have the least access to open spaces (Harris and Pinoncely, 2014; Kjellstrom *et al.*, 2007). Areas already exposed to high levels of transport noise and air pollution, such as near busy roads, airports and railway lines, may also be more affordable to poorer residents.

1.6.1 Exposure vs. vulnerability

Whilst it is clear that both rich and poor are affected negatively by pollution, it is not clear whether both are affected to the same extent. **Exposure, sensitivity and vulnerability** are three key concepts regarding pollution's potential impacts on health. Is a person or community more likely to be affected by pollution because they are more exposed to it, because they have increased sensitivity, or because they are more vulnerable to its effects? Although these concepts are linked (high exposure or sensitivity can increase vulnerability; high exposure can also increase sensitivity, for instance), it is also important that they are differentiated. As some studies show (**discussed in Part 3 of this report**), people exposed to high levels of pollution do not necessarily have a higher risk of ill health than people exposed to lower levels of pollution.

1.6.2 Socioeconomic status and exposure

Increasingly studies are seeking to understand whether socioeconomically disadvantaged populations are consistently exposed to higher levels of air and noise pollution, and, if so, whether there may be long-term negative health consequences for these populations (see **Part 3** for further discussion of these studies). Studies to date suggest that more deprived communities are more likely to be more exposed to air and noise pollution.

There are many interacting factors that affect exposure to noise and air pollution, and its impacts: ranging from the political economy to aspects of the built environment. Monetary wealth is one important factor, but it is not the only factor. In social research, privilege or deprivation status is calculated by combining a number of different factors to generate indices of deprivation (Pelletier *et al.*, 2013). See **section 3.1.1** for further details of deprivation indices.

The associations between exposure, health outcomes and socioeconomic status are very complex due to these many interacting variables. Thus, health outcomes must be viewed in a wide context of all possible factors, especially as it is difficult to separate the influence of some these factors in studies carried out in real-life settings (CSDH, 2008).

8. *http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:l28186*
9. *http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.158.01.0131.01.ENG*

1.6.3 Socioeconomic status and vulnerability

Socioeconomically deprived populations may suffer increased health problems related to noise and air pollution compared with less socioeconomically deprived populations, not only because they are exposed to higher levels of pollution, but also because they are more *vulnerable* tto the effects of pollution (WHO, 2010). This 'vulnerability hypothesis' was proposed in the 1990s but it is still less well understood than exposure effects in deprived populations.

The health of deprived populations tends to be worse overall than that of more affluent populations (WHO, 2010). The risk of chronic diseases, such as heart disease — associated with both noise and air pollution, is already higher for people of low socioeconomic status, for instance (**see 2.2–2.4** for further details).

Together, evidence from studies could suggest that deprived populations suffer worse health effects from noise and air pollution through increased exposure and increased vulnerability to the effects of exposure. Evidence for this proposed 'double burden' is considered in further detail in sections **3.2.1 and 3.2.2**.

Lifestyle and behavioural factors, which are linked to broader factors, such as income and education, may also play a role in vulnerability. They also make the picture more complex by adding to the many risk factors (**see 3.3**) experienced by deprived populations (WHO, 2010). These include diet, commuting times, smoking (and passive smoking) and alcohol consumption, and other lifestyle factors like physical and sports activity.

Bilger and Carrieri (2013) posit that low quality neighbourhoods are strongly health-damaging. They also cite several studies which support the assertion that a high concentration of poor, less-educated individuals living in an area might negatively affect health due to the unhealthy lifestyles that are more common among people in deprived socio-economic circumstances (in addition to pollution levels and other neighbourhood factors). On the other hand, people who are already healthier or more physically active — through self-selection based on their initial health status — may be more likely and able to live in healthier neighbourhoods with better access to green spaces and sports facilities (Bilger and Carrieri, 2013). This bias may make it more difficult to assess the effects of socioeconomic status on pollution-related health effects, with respect to either exposure or vulnerability. However, few studies have attempted to deal with this issue.

A person's coping strategies and resources may also reduce their exposure to pollution and thus their vulnerability. For instance, Hajat *et al.* (2015) ccomment that higher socioeconomic groups are more likely to be able to afford to live in better constructed houses. In addition, they have more 'social capital'. Social capital, in this case, may be political influence used to prevent polluting land uses, such as factories and roads, from being built in the local community.

Traffic jam on German highway /A100 in Berlin © querbeet @iStock, 2013.

Part 2: The possible contribution of noise and air pollution to health impacts

As outlined in Part 1, exposure levels and vulnerabilities of different socioeconomic groups to noise and air pollution may vary, leading to unequal health impacts. Therefore, in order to inform the later discussion on health inequalities, Part 2 of this report outlines proposed pathways towards the negative health consequences of noise and air pollution, as well as some of the most likely health impacts.

2.1 Pathways to poor health

Air and noise pollution contribute to 'causal pathways' towards negative health impacts, that is, they are part of a combination of risk factors which may lead to poor health. 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

Streets and neighborhoods of Athens, Greece. © Starcevic @iStock, 2016.

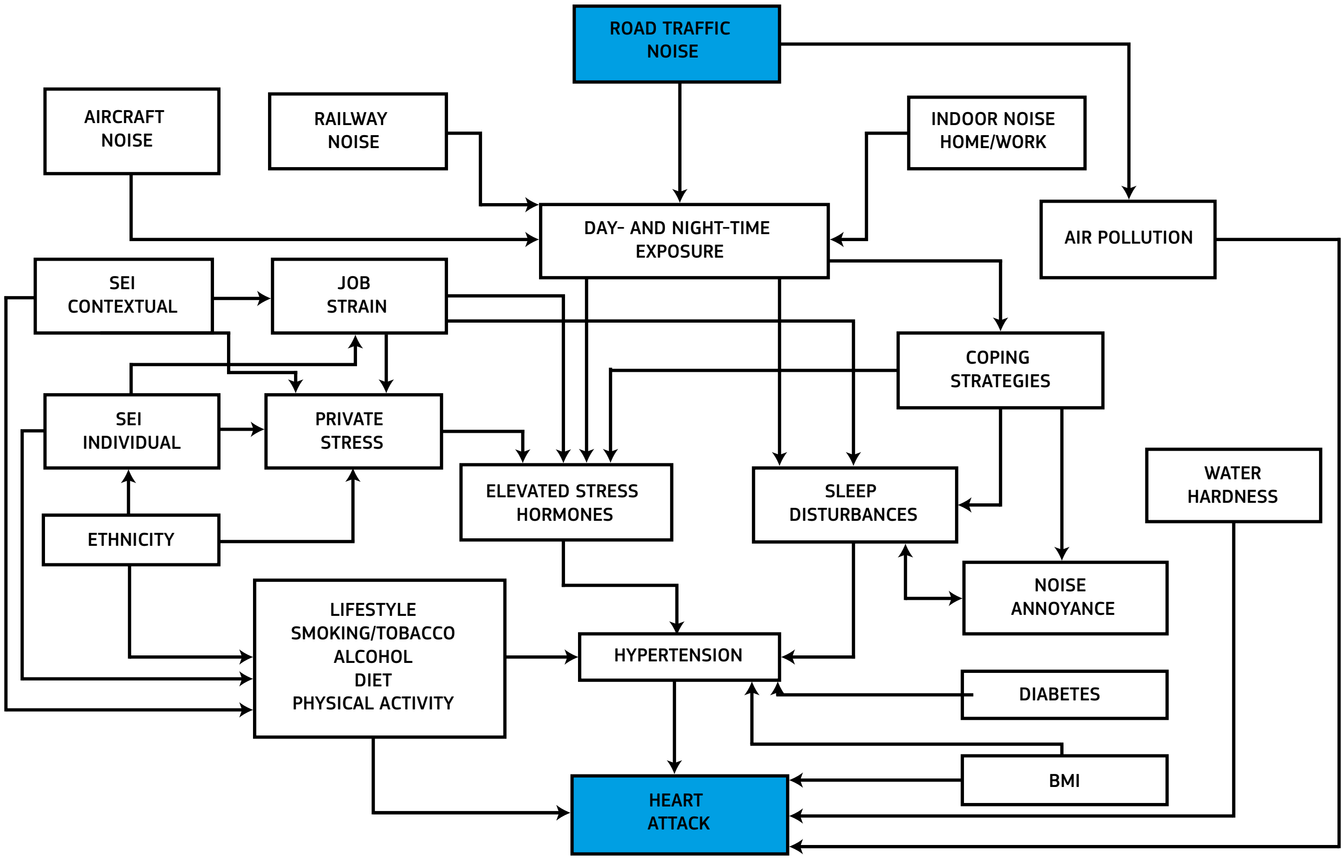


Figure 2: Association between road traffic noise and myocardial infarction (heart attack). © European Union, Lekaviciute *et al.*, ENNAH - European Network on Noise and Health, EU Project no. 226442, JRC Scientific and Policy Reports EUR 25809 EN (2013). Redrawn.

environmental stresses (Lekaviciute *et al.*, 2013). Thus multiple pathways, involving both increased exposures and increased vulnerabilities, could lead towards a health outcome, such as heart disease.

Figure 2 outlines possible causal pathways between road traffic noise and myocardial infarction (heart attack). Many factors are shown to add to the pathway and affect the risk. As well as air pollution, they include diet, job-related stress and BMI (body mass index). Socioeconomic factors are represented as socioeconomic indices (SEI) and may be important in understanding an individual's risk, because they affect the lifestyles and behaviours (e.g. diet) that determine exposure and vulnerability to pollution for each person.

2.2 Health impacts

This section introduces four areas of health affected by noise and air pollution: respiratory health, cardiovascular health, mental health and sleep disturbance. Outside of these four areas, there are many other known and proposed health impacts of air and noise pollution. There are three possible reasons for a correlation of increased health impacts with low socioeconomic status. Firstly, increased exposure to the pollution. Secondly, people of lower socioeconomic status could be more sensitive to each health problem, because of underlying or associated illness, life habits or addictive behaviours, such as smoking. Thirdly, given the lack of resources or access to deal with health problems, higher workplace, indoor and outdoor exposure from the living and working environment, and lower mobility, they could also be more vulnerable to pollution's effects. Most studies seem to acknowledge all aspects to an extent; evidence so far suggests that these interweaving factors are still being unpicked.

> *...multiple pathways, involving both increased exposures and increased vulnerabilities, could lead towards a health outcome, such as heart disease.*

2.3 Respiratory health

Various studies show that there is an association between exposure to common air pollutants and an increased risk of viral respiratory infections, chronic cough and bronchitis, pneumonia and influenza (Kelly, 2014). Looking at individual pollutants' effects, PM2.5 and PM10 can lead to illness and death from lung cancer, asthma aggravation and other respiratory and cardiopulmonary diseases and increased risk of viral respiratory infections SO2, NOx and ground level O3 can also worsen asthma symptoms (NRDC, 2015).

Noise pollution has also been related to respiratory illness, although there is much less research on this than for air pollution. A study in Madrid, for example, found that higher noise levels were associated with a significantly increased risk of respiratory mortality in people aged over 64 years. This was even after the researchers had taken account of the effects of air pollution (PM2.5 and NO2). The researchers suggest that this association is linked to high levels of cortisol (the 'stress hormone') being released during stressful situations, which can increase the risk of asthma and chronic bronchitis (Tobias *et al.*, 2013).

There is some debate among scientists over whether asthma and respiratory allergies are more likely to occur among higher or lower economic groups (Hedlund *et al.*, 2006; Poyser *et al.*, 2002; Hancox *et al.*, 2004; Eagan *et al.*, 2004). Overall, however, respiratory diseases do appear to be more common among lower socioeconomic groups for a number of reasons; air pollution and possibly noise pollution are two of the many risk factors.

It should be noted that there are some crossovers between respiratory and cardiovascular diseases, as the cardiopulmonary (heart and lungs) system is highly connected (WHO, 2013a).

2.4 Cardiovascular health

Research indicates that both air and noise pollution are contributory factors to cardiovascular disease. A growing body of epidemiological and clinical evidence, for example, has increased concerns about the potential relationship between air pollution and heart disease and stroke (Brook *et al.*, 2004). PM and CO increase blood pressure and a number of studies show that the risk of both heart disease and mortality increase with greater exposure to PM2.5 and PM10 (Zeka *et al.*, 2004; discussed in Lee *et al.*, 2014; Maté *et al.*, 2010).

For noise effects, there are some high-quality, population-level studies linking heart disease to environmental noise (WHO Europe, 2011), although two recent papers argue that the evidence for the link between traffic noise and heart disease still needs to be strengthened (Banerjee *et al.*, 2014; Vienneau *et al.*, 2015). The so-called 'general stress

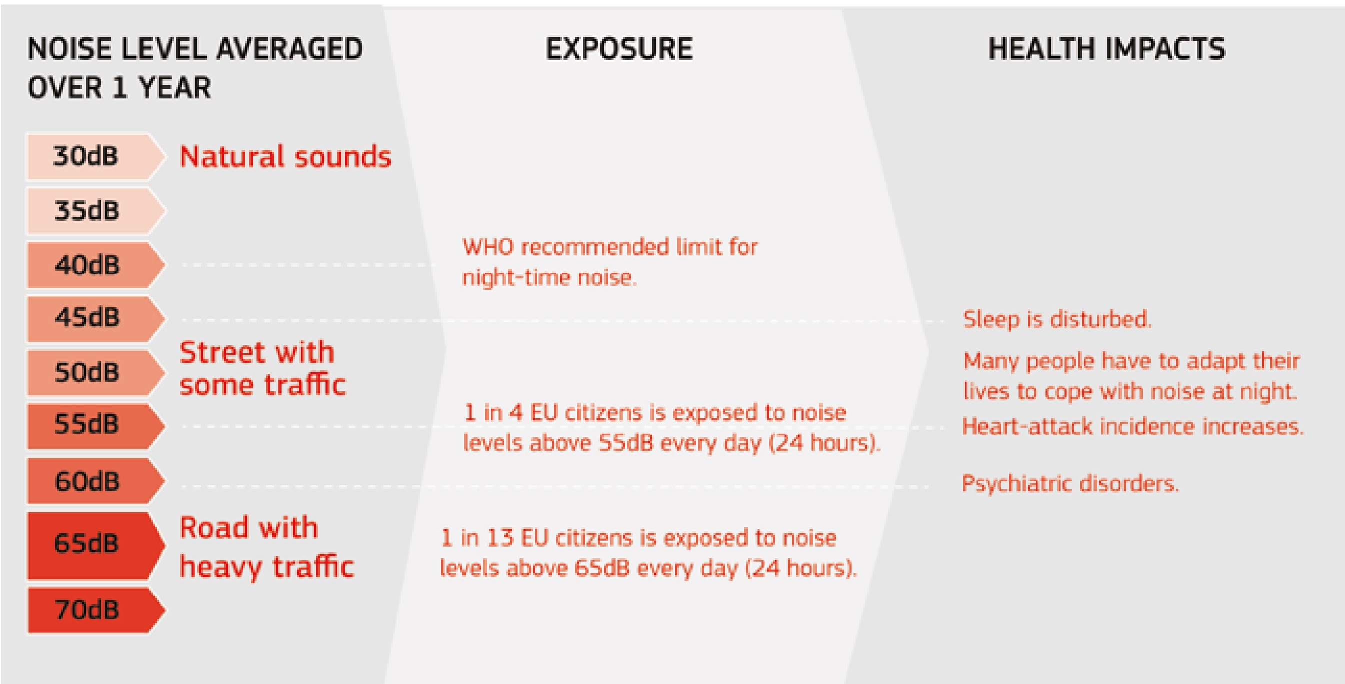


Figure 3: Links between noise levels, exposure and health impacts (adapted from Biamp Systems (n.d.). Redrawn.)

model' may explain the potential link between noise and heart disease. This describes the way that the body responds to stress and it has been suggested that noise activates the nervous system and triggers the release of stress hormones (Hansell *et al.*, 2013; Lekaviciute *et al.*, 2013). One of the main outcomes of these stress processes is thought to be raised blood pressure.

Again, people from lower socioeconomic backgrounds are more vulnerable to coronary heart disease due to a wide range of reasons. In developed countries, low socioeconomic status is associated with a number of risk factors for heart disease, including high blood pressure, diabetes and obesity (Mackay and Mensah, 2004). Higher levels of air and noise pollution, and increased duration of exposure, add to these risk factors.

2.5 Mental health

Vulnerable groups, such as those living in poverty or with long-lasting illnesses, may be more sensitive or vulnerable to mental health problems (WHO, 2013b). Noise and air pollution may increase this risk of mental illness. It is not entirely clear how exactly they affect mental health, but it is possible that annoyance in the case of noise and tissue damage or inflammation in the case of air pollution may play a role.

Stansfeld and Matheson (2003) suggest that annoyance caused by noise can lead to more serious or less serious psychological effects, but that this risk is influenced by an individual's perceptions and coping strategies. Thus, noise's impacts are very unique to the individual, even if there are also are socioeconomic and community influences. Some evidence for differences in vulnerability to mental health problems in relation to socioeconomic status and noise/ air pollution is discussed in **sections 3.2.1** and **3.2.2**.

Air pollution is not usually thought of as being linked to mental health problems. However, a survey of 71 271 women found increased symptoms of anxiety among those exposed to high levels of PM2.5 over the long-term (Power *et al.*, 2015). The study's authors suggest that PM2.5 may cause anxiety through oxidative stress (damage caused by reactive oxygen) and generalised inflammation, although this theory is not yet proven.

2.6 Sleep issues

There is good evidence for the impacts of noise on sleep (Stansfeld and Matheson, 2003). The links between air pollution and sleep are not well studied, although there is some evidence that being exposed to higher levels of PM may reduce the duration and quality of sleep (Fang *et al.*, 2015).

Hours of sleep by ashleyamos @Pixabay, 2014.

Poor sleep is linked to a range of other health impacts, such as hypertension, diabetes, a weakened immune system and mental health problems, including depression and anxiety (Arber *et al.*, 2009; Robotham *et al.*, 2011). Therefore, the impacts of noise on sleep cannot be considered in isolation, but rather as part of a range of possible health problems that may interact with each other. There appears to be little research to date which has measured both noise exposure and its impacts on sleep in different socioeconomic groups. However, selected studies are discussed in **section 3.2.1** along with other evidence for exposure and vulnerability differences in deprived populations.

One important factor when considering socioeconomic differences in sleep patterns is shift work, which is more likely to be conducted by people from lower socioeconomic groups. This may make minority, low-income and less educated populations more vulnerable to sleep problems (Givens *et al.*, 2015).

Part 3: Associations between socioeconomic factors and the health outcomes of noise and air pollution

In the third part of this report, we take a more detailed look at the existing evidence for possible links between socioeconomic situation and the health outcomes of noise and/or air pollution. We explore multiple components of socioeconomic status, recognising that income alone cannot determine exposure to pollution or pollution's impacts. We also consider how socioeconomic factors fit within a wider range of interrelated factors that potentially influence health, including individual lifestyles and behaviours.

3.1 Methodological issues and complexities of research

Studies in this field use a wide variety of methods to measure aspects such as exposure and socioeconomic status, and collect data from study participants. There are varying ways to record metrics on exposure assessment, and this results in some incoherence between studies. The variety of qualitative and semi-qualitative socioeconomic metrics has emerged as a significant issue, as it makes meta-analyses and horizontal comparisons difficult or less meaningful. For every study it is necessary to look in detail at the way impacts were measured as each method has different advantages and disadvantages. This understanding of study design can help users of research interpret findings and consider whether and how to compare the results of different studies.

3.1.1 Defining socioeconomic status

Different studies define socioeconomic status in different ways. Definitions may include one, some or all of the following factors:

- Income
- Education
- Property ownership
- Type of housing
- Employment
- Other measures of deprivation/privilege

Within these categories, indicators are used to estimate levels of deprivation/privilege. The estimates could be for individuals or households, or for broader scales, such as neighbourhoods and regions.

Some studies use just one measure of socioeconomic status. For example, Pearce *et al.*'s 2013 study, which investigated social inequalities in exposure to air pollution in the EU, used one indicator: gross domestic product (GDP) per capita (results are presented in **section 3.2.2**).

Other studies may consider larger numbers of indicators to create combined measures of socioeconomic status.. These indices may be *additive*, meaning results are calculated simply by adding up the scores from a set of indicators, or *multidimensional*, meaning that the relationships between the different indicators are first analysed before the most relevant indicators are selected (Pelletier *et al.*, 2013).

An example of a study which used an index is Battaner-Moro (2010) which explored access to quiet areas in a UK city. This used the English Indices of Deprivation which includes 38 indicators under seven domains; Income; Employment; Health and Disability; Education, Skills and Training; Barriers to Housing and Other Services; Crime; and Living Environment (McLennan *et al.*, 2011) (**section 3.2.1** describes the results).

3.1.2 The indirect influence of socioeconomic status

Socioeconomic factors, such as low income, do not have direct impacts on health. Instead, they may lead to increased exposures to risk factors that in turn increase the risk of certain impacts. Proving cause and effect is not straightforward, and more long-term research (**see 3.1.3**) is needed to track changes in exposure and health status over time.

Putrik *et al.* (2015) describe different examples of how socioeconomic status may influence health in relation to pollution. One possible explanation for increased exposure linked to lower socioeconomic status is that people on lower incomes choose to move to deprived and polluted areas as a way of living cheaply near to a place of work. This explanation refers to a 'compositional' or 'selective' influence on neighbourhood health, in which people moving in may already be in poor health due to factors linked to their lower socioeconomic status. This explanation is relevant to particular regions and property markets — for example, in areas under flight paths near to Paris and its airports (Pelletier *et al.*, 2013). An alternative explanation, favoured by Putrik *et al.* (2015), is the 'contextual' effect, where it is the local environment that causes the poor health.

A combination of both effects could occur in areas affected by noise and air pollution. People on lower incomes are more likely, for example, to live near main roads where rents may be cheaper (Schmit and Lorant, 2009). Deprived and low-quality environments may also expose the local

Urban Housing © querbeet @iStock, 2014.

population to higher levels of noise pollution due to poor sound insulation and higher population density. In Europe, the association is a mixed one. For example, in London, both traffic density and most air pollutant concentrations are highest in the east, where many poorer population groups live (Forastiere *et al.*, 2007). Also, the most deprived areas of Paris — i.e. in the northern and eastern fringe, along the périphérique (ring road) — overlap somewhat with the areas most polluted by NO2 — along the périphérique and the Seine river, and in the north-western parts of the city. Overall, people in low SES areas were shown to be more vulnerable to high air pollution episodes (Deguen *et al.*, 2015). Note, however, that wealthier residents in desirable, city centre locations may also be exposed to high levels of air and noise pollution, as in Rome, Bristol and Rotterdam (Forastiere *et al.*, 2007; Fecht *et al.* 2015) (**see 3.2.2**), for instance. From a different perspective, in a cohort study of air pollution and mortality in Oslo, there was no relation shown between exposure to NO2 at home and socioeconomic status (Forastiere *et al.*, 2007).

3.1.3 Methodological challenges in study design

We consider here some of the challenges researchers face in carrying out studies in this field.

Cross-sectional vs. longitudinal research

In terms of how data are collected, being able to distinguish between two types of study design — cross-sectional and longitudinal — may be useful for this report.

Cross-sectional — these studies collect data from participants at a particular point in time as a snapshot of a study population (Payne and Payne, 2004). It is difficult to build strong associations between cause and effect from these kinds of studies because the data only represent the situation at a certain time. The data may be subject to random variations and potentially unknown external influences at that time. It would be possible to make links between symptoms and social factors, such as deprivation levels, within a cross-sectional study, but not to show how symptoms increase or decrease over time as the social environment changed.

Longitudinal — these studies collect data from the same participants or locations a number of times over a certain period. They allow researchers to track the effects of social change or change in exposure levels *over time* (Payne and Payne, 2004). In a 2013 report, the European Network on Noise and Health called for more longitudinal, as opposed to cross-sectional, studies in research on the impacts of noise, because longitudinal methods are 'more robust' (Lekaviciute *et al.*, 2013). However, opportunities for longitudinal studies are rarer because they are more expensive and time-consuming, and data may not be available for analysis for many years (Payne and Payne, 2004).

Self-reported data

One common problem with research in this field is the use of subjective measures, as with self-reported noise levels. Air and noise pollution levels can be measured objectively through pollutant concentrations and decibel measurements. However, for certain studies, self-reported data may be considered more appropriate. For example, an individual's perception of noise gives a better picture of the discomfort it may cause, since some people are more sensitive to certain noises than others (Schmit and Lorant, 2009). Self-reported data may also be provided on the health effects of noise, even though it is not always the case that self-reported and objectively measured data on health issues agree, including on heart disease (Mosca *et al.*, 2013) and sleep disorder (Landry *et al.*, 2015). In some cases, a person's 'world view' may bias the information they provide on pollution levels and its effects — perhaps because they have a very negative or very positive view of their life and surroundings. This is referred to as 'one-source bias (Putrik *et al.*, 2015).

Individual exposure

Even where more objective measurements are used, these do not necessarily represent the levels of air or noise pollution that individual study participants are actually exposed to. Most studies in this field look at average exposures, across a neighbourhood or city, for example. Furthermore, researchers often assume that people spend most of their time at home (Tenailleau *et al.*, 2015). However, what is not often considered is the impact of exposures at work and when commuting to work, whether different socioeconomic groups spend different proportions of their time at work and whether lower socioeconomic status carries an increased risk of working in a polluted environment. 'Exposure' is typically measured in terms of average conditions for a specific area or region, and not all members of the study population will be exposed to the same level of pollution (Pearce *et al.*, 2013). In addition to different exposure levels at work or while commuting, other, seemingly minor differences in housing conditions, urban design or lifestyle may have a large impact on exposure levels and are linked to socioeconomic factors, but are not often taken into account. For example, Banerjee *et al.* (2014) collected data on outdoor noise levels and even modelled noise levels at specific locations corresponding to the participants' own homes, but did not account for building parameters such as storey, or consider how different participants would be affected due to different working hours.

Other methodological issues

Other potential problems with studies in this field include:

- low numbers of participants making it difficult to show effects (Stansfeld and Crombie, 2011);
- confounding variables, as in studies on air pollution that do not take into account the effects of noise pollution, and vice versa, as well as other factors that may be unaccounted for;
- unconfirmed physiological (and other) effects of pollutants, which have, for instance, only been studied at high exposure levels (Hansell *et al.*, 2013);
- studies that are undertaken in a specific country, region or neighbourhood may be of limited use to understanding the factors — including socioeconomic factors — that affect other locations (Miles, 2012). For example, much of the evidence exploring links between socioeconomic status and mortality comes from the UK, perhaps because socioeconomic differences have traditionally been of interest in this country (Prescott and Vestbo, 1999). Thus, local municipalities and practitioners must gain an understanding of local influences on noise and air pollution exposures and impacts in order to address pollution at a local level.

3.2 Socioeconomic status and pollution: evidence of links with health

Existing research, summarised in the following sections, tends to find that disadvantaged communities are often exposed to higher levels of air and noise pollution than more advantaged groups. However, this is not a universal pattern and there are some notable exceptions to this general picture; for instance, many city centre locations are very desirable for wealthier residents. Importantly, exposure to pollution alone does not determine health outcomes. Rather, those who are more vulnerable to its effects appear more likely to suffer poor health from the onset.

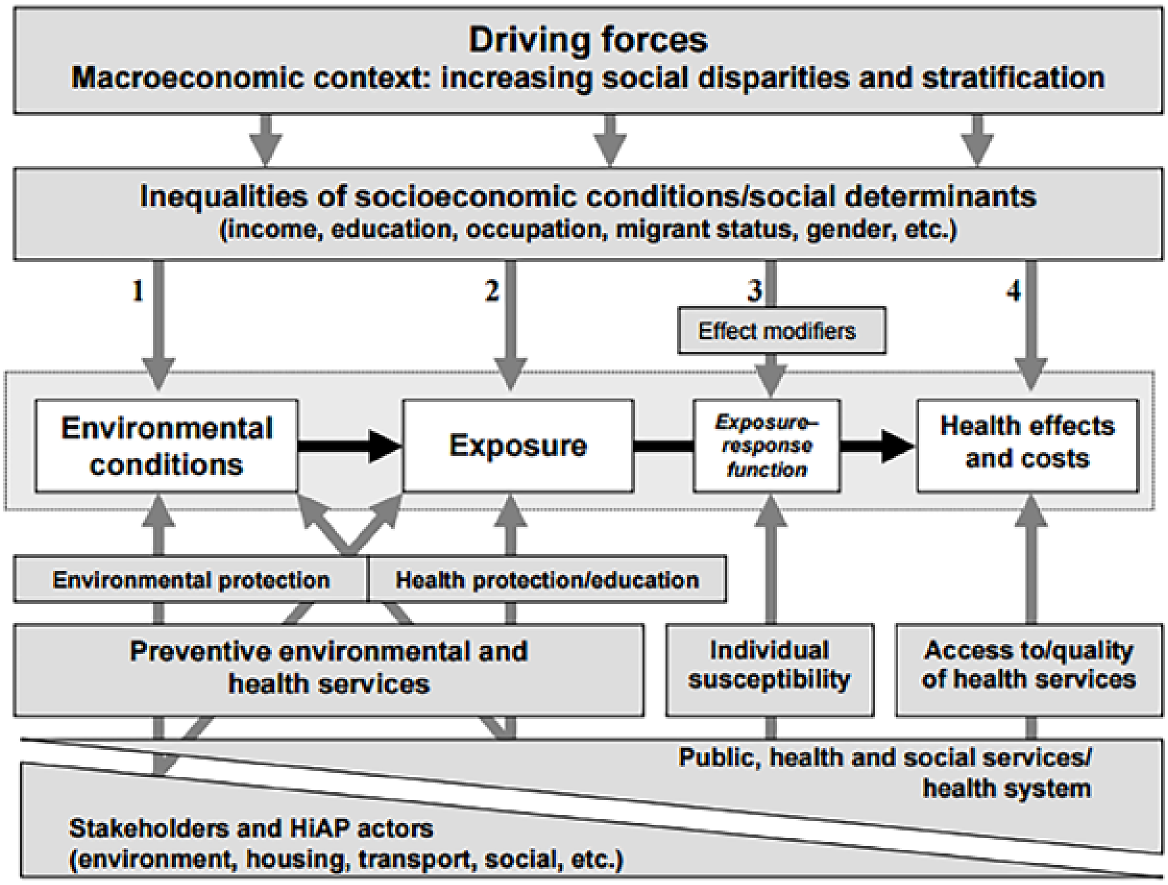


Figure 4. WHO framework model on social inequalities and environmental risks. © World Health Organisation, Environment and health risks: a review of the influence and effects of social inequalities, WHO, 2010.

As explained in **section 3.1**, many different types of studies are used to assess exposure and vulnerability to noise and air pollution and to make links to socioeconomic factors. It is therefore important to consider the methods used on a case-by-case basis and to appreciate that the links between pollution and socioeconomic status are not straightforward.

3.2.1 Noise pollution

Although there is less research on links between noise pollution and socioeconomic factors, compared with corresponding air pollution studies. Many existing studies have identified deprived areas that are noisier outdoors than affluent areas. Dale *et al.* (2015), found that there was a strong correlation between noise exposure and all low socioeconomic indicators studied for Montreal. However, given the inconsistency with a number of other studies, they suggest that the links between socioeconomic status and noise exposure are likely to be highly dependent on the local situation in each area studied.

Exposure

We consider here studies that explore differences between socioeconomic groups in exposure to noise pollution. One study that found a link between deprivation and exposure is Pelletier *et al.* (2013), which looked at noise and air pollution near to three French airports. The researchers created noise maps (to satisfy the requirements of the European Noise Directive) which could show noise levels for individual buildings. They used an additive deprivation index (with four variables), as well as a multi-dimensional deprivation index (21 variables) using data from a national-level population census. The results show that the most deprived areas contained higher concentrations of people living in houses exposed to levels of air and road traffic noise above certain thresholds.

Some other studies from around the world provide examples of lower socioeconomic groups being exposed to higher levels of noise pollution. For instance, Dale *et al.* (2015) suggest that noise exposure in Montreal, Canada, increases in a largely linear fashion as socioeconomic status decreases. This cross-sectional study assessed socioeconomic status using five different indicators as well as two different deprivation indices combining multiple indicators. The authors measured outdoor noise levels at 87 sites via decibel measurements during a two-week period.

Elsewhere, a 2003 study based on German Federal Health Survey statistics from the 1990s suggests that people of low socioeconomic status face an increased burden from traffic noise and feel more affected by it (Hoffman *et al.*, 2003). Noise exposure is hard to measure; individuals' perceptions of how affected they are by noise may provide important information about exposure levels, but it should be remembered that these perceptions are very subjective. A second German study found that among 7275 survey

Study	Brief description	Key air emissions
Dale *et al.* (2015)	Neighbourhood level study on SES and noise levels in Montreal, Canada.	Lower SES linked to higher noise exposure.
Pelletier *et al.* (2015)	Neighbourhood level study on SES and noise levels around three French airports.	Greater deprivation linked to higher levels of noise exposure.
Huss *et al.* (2010)	Nationwide survey of aircraft noise and air pollution in relation to heart attack death in Switzerland.	Lower SES linked to higher noise exposure but not to higher risk of heart attack death. Living longer in an exposed location increases risk.
Hoffman *et al.* (2003)	Self-report survey of German citizens collecting data on SES and health.	Lower SES linked to greater exposure to traffic noise pollution.
Kohlhuber *et al.* (2006)	Nationwide survey of SES and environmental exposures, including noise, in German households.	Lower SES linked to greater self-reported exposure to noise.
Fyhri and Klaeboe (2006)	Survey of traffic noise annoyance combined with building-level noise measurements in Oslo and Drammen, Norway.	High-income populations can afford to live centrally in quiet neighbourhoods within small- and medium-sized cities. Not confirmed in large cities.
Kamphuis *et al.* (2013)	Self-report survey of life-course risk factors for heart disease death in Eindhoven, Netherlands.	SES in men, neighbourhood noise and traffic noise linked to risk of heart disease death.
Putrik *et al.* (2015)	Self-report survey of neighbourhood nuisance, including traffic noise, and depressive symptoms in Maastricht, Netherlands.	Greater exposure to car and railway traffic, and lower educational status, linked to increased depressive symptoms.
Arber *et al.* (2009)	Self-report study, representing UK population, on SES and sleep problems.	Lower SES linked to increased sleep problems. Multiple contributing factors, including neighbourhood noise.
Saremi *et al.* (2008)	Self-report survey of sleep problems and noise exposure at French chemical plant.	Shift workers suffered more from noise-aggravated sleep problems compared with day workers. Older workers more vulnerable to noise/shift work effects.

Table 3: Summary of cited studies on socioeconomic status and noise pollution. SES = socioeconomic status.

respondents, those of lower educational and occupational status, those who had lower incomes and those living in poorer housing conditions were more likely to report higher levels of noise exposure (Kohlhuber *et al.*, 2006).

Exposure to quiet areas may also affect wellbeing. One UK study considered inequalities in access to quiet areas (defined in response to the Environmental Noise Directive) in the city of Southampton (Battaner-Moro, 2010). The results indicated that those living in more deprived areas had less access to quiet areas. The study used the English Indices of Deprivation to estimate deprivation status; that is 38 indicators under seven domains: Income; Employment; Health and Disability; Education, Skills and Training; Barriers to Housing and Other Services; Crime; and Living Environment (DCLG, 2011). Different domains have different weights —income is weighted at 22.5%, whilst Living Environment is weighted at 9.3%. Living Environment incorporates the condition of social and private housing, as well as indicators relating to central heating, air quality and road traffic accidents.

A number of studies have found that many city-centre locations are favoured by wealthier residents. This was found to be the case in Oslo and Drammen, Norway, for example, by Fyhri and Klaeboe (2006). Although people on higher incomes in this study lived closer to central areas that were noisier on average, they were more capable of 'paying themselves out of the noise' because they could afford to live in relatively quiet locations in the centre. The point about people being able to pay to mitigate the effects of noise is crucial, i.e. they are less vulnerable, but is still largely an assumption, however, which needs to be supported by further evidence.

Vulnerability

We consider here studies that explore differences between socioeconomic groups in their vulnerability to noise pollution. It makes sense to expect the health impacts of noise pollution to be more common and more severe in lower socioeconomic groups, for whom health is, on average, poorer. Indeed there is evidence for increased vulnerabilities in a number of deprived populations. For example, one Dutch study of over 10 000 residents of Eindhoven city found that socioeconomic status in childhood was associated with heart disease deaths in adulthood, but only in men (Kamphuis *et al.*, 2013). (Women made up 53% of the study sample.) Material, behavioural and psychosocial risk factors associated with heart disease were largely responsible for inequalities in heart disease deaths. Material factors included neighbourhood and traffic noise. These risk factors were linked to men's socioeconomic status as adults, which was strongly influenced by their socioeconomic status as children. In this case, socioeconomic status was assessed at 12 years of age by their father's job and in adulthood by educational achievement. This study suggests that socioeconomic status, noise and a range of other risk factors contribute to a 'pathway' to death from heart disease. According to the researchers, the lack of a similar pathway in women may simply be due to larger numbers of missing data for childhood socioeconomic status. However, a recent review also suggested that men face a greater risk of noise-related heart disease than women (Vienneau *et al.*, 2015). These results illustrate how noise may only be one risk factor among many that contribute to health impacts.

Turning to impacts on mental health, a self-report study based on data from 9879 residents of the Dutch municipality of Maastricht found that residents of neighbourhoods exposed to more car traffic and railway 'nuisance' reported worse mental health — 'nuisance' in this case referred to noise as well as smell and aggressive driving (Putrik *et al.*, 2015). Symptoms of depression were more commonly reported by people with lower levels of education. This suggests residents of lower socioeconomic status are more vulnerable to depression. Although the researchers used self-reported data, they note that they used a statistical model designed to reduce the effect of individual perceptions on the results.

Some studies have provided examples of lower socioeconomic groups who suffer sleep problems which are possibly — and partly — caused by noise. In one UK study, for example, results from a survey of 8580 people found that self-reported sleep problems were more common for people who are on lower incomes, poorly educated, unemployed or living in public housing (Arber *et al.*, 2009). The researchers say that neighbourhood noise is one of many factors that could have been responsible for this association between socioeconomic status and sleep quality, however, it was not measured in the study itself. The researchers drew on evidence from other studies to explain the association between low socioeconomic status and disturbed sleep. Factors other than noise include crowding, poor insulation, anti-social behaviour and anxiety about unemployment or income.

Another sleep-focused study by Saremi *et al.* (2008) found that exposure to industrial noise at work aggravated fatigue more for shift-workers than for day workers. Older workers were more susceptible to the combined effects of noise and shift work. Although the researchers did not assess socioeconomic status, these results suggest another potentially complex interaction between noise, sleep, socioeconomic status and lifestyle factors, as shift-working may be more common in deprived populations.

Not all studies find a link between socioeconomic status, exposure and vulnerability. For instance, a large study (on both aircraft noise and air pollution) of 4.6 million Swiss citizens measured aircraft noise levels (in decibels) in conjunction with heart attack deaths (Huss *et al.*, 2010). Socioeconomically deprived households tended to be in areas exposed to higher levels of aircraft noise than the population in general. However, they did not appear to be at increased risk of dying of a heart attack. Rather, the association was strongest for people who had lived at the same highly exposed location for at least 15 years, with no differences between socioeconomic groups. These results indicate that it is the duration of exposure that is linked to heart attack death. They also found an increased incidence of heart attack in people living close to a major road, and suggest that high levels of traffic noise might explain this finding (or they also posit the increased risk may be due to ultrafine particles, which they did not test for).

3.2.2 Air pollution

As with noise pollution research, results of studies which explore potential links between air pollution, socioeconomic status and health vary by region, locality and neighbourhood. In some parts of the world there is good evidence that people from lower socioeconomic groups are exposed to higher levels of air pollution, although the latest research suggests that this is not always the case in Europe, or in all cities globally. Regardless of exposure levels, however, the health effects may still be worse for deprived populations due to their increased vulnerability.

Exposure

We consider here studies that explore differences between socioeconomic groups in exposure to air pollution. A recent global review analysed evidence from 37 relevant studies, with the vast majority (32) coming from North America and Europe (Hajat *et al.*, 2015). Overall, the North American studies showed that people of lower socioeconomic status were exposed to higher concentrations of air pollutants than people of comparably higher socioeconomic status. Exceptions to this pattern were New York City, Toronto and Montreal, where it seems central locations are still desirable to the cities' wealthier populations. A limited number of studies from New Zealand, Asia and Africa also provide examples of lower socioeconomic groups who are exposed to more pollution. European studies revealed mixed results. In Europe, several studies observe an association between lower socioeconomic status and high pollution exposure, but some other studies find people of higher socioeconomic status living in polluted areas. This may be due to gentrification of inner city areas (Fecht *et al.* 2015). However, living in areas with higher pollution levels does not necessarily equate to higher exposure levels at an individual level. As Hajat *et al.* (2015) point out, people from higher socioeconomic groups may have the resources to protect themselves, for example, through paying for private transport and working indoors, or through access to better medical care.

Air Pollution Level 5 London, UK, April 30 2014. CC BY 2.0 David Holt, Flickr, 2014.

Study	Brief description	Key air emissions
Hajat *et al.* (2015)	Global systematic review of studies on SES and air pollution.	Trend for lower SES to be linked to higher exposure, but with mixed results in European region.
Pearce *et al.* (2013)	EU-wide study on regional differences in SES and in PM10 and O3 levels.	Lower SES linked to higher exposure to PM10 and O3.
Fecht *et al.* (2015)	Neighbourhood-level study of deprivation and PM10 and NO2 concentrations in the Netherlands and England.	Greater deprivation linked to higher exposure to PM10 and NO2.
Goodman *et al.* (2011)	Postcode-level study of deprivation and NOx concentrations in London, UK.	Greater deprivation linked to exposure to higher levels of NOx overall. Some affluent groups had high exposures.
Tenailleau *et al.* (2015)	Neighbourhood and building-level study of deprivation and pollution concentrations in Besançon, France.	Relationship between SES and exposure depends on measurement scale.
Gray *et al.* (2013)	Investigation of links between SES and race, and pollution concentrations, in North Carolina, USA.	Lower SES linked to higher PM2.5 exposure but lower O3.
Su *et al.* (2011)	Neighbourhood-level study of SES and pollution concentrations in Los Angeles, USA.	Lower SES linked to higher NO2 and PM2.5 exposure, but not to higher O3.
Forastiere *et al.* (2007)	City-level study of SES, PM10 exposure and associated deaths in Rome, Italy.	Lower SES linked to lower PM10 exposure but higher associated risk of death.
Romieu *et al.* (2012)	City-level study of SES and health impacts of PM10 and O3 in Latin American cities.	Lower SES linked to higher risk of dying from chronic obstructive pulmonary disease.
Huss *et al.* (2010)	Nationwide survey of aircraft noise and air pollution in relation to heart attack death in Switzerland.	No link between heart attack death and SES, air pollution or education.

Table 4: Summary of cited studies on socioeconomic status and air pollution. SES = socioeconomic status.

Another European study (Pearce *et al.* 2013) (not included in Hajat *et al.*'s 2015 review) looked at geographical and social differences in exposure to air pollution across the EU. It assessed deprivation levels based on GDP per capita. Although it only considered differences in exposure between relatively large regions, it is one of very few studies considering social inequalities across Europe. It shows that deprived populations in Europe are likely to live in areas with higher average air pollution levels than more privileged populations. The researchers averaged pollution concentrations across areas containing 150 000–800 000 people or 800 000–3 000 000 people, over the short-term (daily) as well as the long-term (yearly). Although PM10 and O3 were broadly within EU limits in 2006 and 2010, PM10 levels were around 30% higher in the most socioeconomically disadvantaged regions compared with the least socioeconomically disadvantaged regions, over both the short- and long-term. Furthermore, this gap remained stable between 2006 and 2010, despite overall pollution levels becoming lower. For O3, concentrations were 30–40% higher in disadvantaged regions over the long-term.

Fecht *et al.* (2015) is another example of a European study. The researchers analysed PM10 and NO2 concentrations experienced by different socioeconomic, ethnic and age groups in England and the Netherlands. Overall, the most deprived neighbourhoods were exposed to the highest concentrations of PM10 and NO2 in both countries. In England neighbourhoods in the most deprived neighbourhoods, compared with the least deprived, experienced, on average, 2.6 ug/m^3 higher levels of PM10 and 7.9 ug/m^3 of NO2. For the Netherlands, the figures were 0.3 ug/m^3 higher for PM10 and 6.1 ug/m^3 for NO2. In the Netherlands the association with deprivation was mainly in urban, ethnically-diverse areas. There were some exceptions to the general pattern, however, particularly for two cities: Bristol in England and Rotterdam in the Netherlands. Here, the most and least deprived neighbourhoods were exposed to similar concentrations of PM10 and NO2. This may also be due to the desirability of city centre homes for more affluent people. These results were produced by calculating annual mean pollutant concentrations for areas of 100 m^2 within geographical units with an average population of 1500. As an indicator of deprivation, the

Lichens by makamuki0 @Pixabay, 2016.

researchers used the percentage of people in each unit who were receiving income support (in England) or benefits (in the Netherlands).

London-based research by Goodman *et al.* (2011) provides some indication of how results can vary according to the methods used, even within a single study. The authors assessed traffic-related air pollution exposure in relation to socioeconomic status, modelling NOx concentrations for 186 424 postcodes. Overall, the results, which included individual-level data collected from 3654 city centre residents, suggested that people of low socioeconomic status were exposed to higher levels of NOx. However, the researchers used two different measures of socioeconomic status. The first was based on deprivation scores obtained using the Index of Multiple Deprivation, which encompasses indicators for income, employment, health, education, crime, housing, services, and indoor and outdoor environment. Using this method, NOx concentrations increased with increasing deprivation scores. There were also associations between NOx exposure and more specific aspects of deprivation. For example, areas with poor housing quality had more air pollution. However, using a second system of socioeconomic classification called ACORN[10], which sorts people into 17 groups based on UK census and public survey data, the researchers found that some of the more affluent groups were exposed to higher levels of NOx. They suggest their study highlights the need to employ more than one method of assessing socioeconomic status, if possible, and to explore the reasons behind exceptions to general trends, for example, affluent city centres.

The effects of conducting research at different geographical scales are demonstrated by Tenailleau *et al.* (2015). The researchers studied the links between neighbourhood characteristics, including deprivation and levels of PM10, NO2, benzene and PM2.5, in the city of Besançon, France. They estimated pollutant concentrations for 4 m2 units and for each of the city's 10 825 residential buildings. In order to assess how different measurement scales affected the relationship between exposure and socioeconomic variables, they tested different 'buffer' zones for pollutant concentrations ranging from 50 to 400 metres around buildings. They found that, in affluent areas, estimated exposure levels tended to decrease as larger scales were used, whereas in deprived areas estimated exposure levels tended to increase at larger scales. Their results show that selecting appropriate measurement scales is a key consideration when

10. http://acorn.caci.co.uk/downloads/Acorn-User-guide.pdf

trying to assess socioeconomic differences in exposure. Similarly, Richardson *et al.* (2013) found that, across Europe, exposure to PM10 was correlated with low household income. However, the study says that the association primarily reflected east-west inequalities. There appeared to be no association when the researchers considered western and eastern European regions separately. Notably, some of the most polluted western European regions were also among the richest. PM10 air pollution was more strongly related to mortality in Eastern Europe, probably due to higher ambient concentrations.

Other, non-EU, studies support associations between socioeconomic status and exposure to air pollutants, but the associations may be different for different pollutants. One study in the state of North Carolina, USA, found that areas of lower socioeconomic status and areas with higher proportions of people from minority ethnic groups were exposed to higher levels of PM2.5 but lower levels of ozone (Gray *et al.*, 2013). Another USA study, Su *et al.* (2011), found that Los Angeles neighbourhoods that were home to greater numbers of residents of low socioeconomic status or from minority ethnic groups were exposed to higher levels of NO2 and PM2.5 but, again, not higher levels of ozone (but note, ozone is usually spatially inverse to NO2 due to atmospheric chemical reactions).

Most of the existing studies on air pollution exposure (and many on noise pollution exposure) focus on transport-related emissions. In a review of inequities in exposure to traffic and air pollution, Pratt *et al.* (2015) suggest that transport infrastructure can be a major source of socioeconomic differences. In their study of air pollution exposure in Minnesota, USA, deprived populations living close to urban centres tended to drive less but were exposed to higher pollution concentrations. Conversely, less deprived populations living further from the centre drove more and were exposed to less pollution.

Vulnerability

Here we explore studies that consider differences between socioeconomic groups in vulnerability to air pollution. Many studies show convincing associations between lower socioeconomic status and certain health conditions that air pollution can affect. For example, using a longitudinal study with a large number of participants, Propper and Rigg (2006) found significant social inequalities in three respiratory conditions in middle childhood. Prescott and Vesbo (1999) argued that the socioeconomic gradient for chronic obstructive pulmonary disease (COPD) seemed as great, if not greater, than any other disease, after adjusting for other influencing factors on COPD development. They concluded that socioeconomic status is the second biggest impact factor (after smoking) on respiratory symptoms, lung function and COPD illness and mortality.

More recently, a Finnish study of 6525 people found that there was an association between lower education levels and COPD, and an association between household income and adult asthma (Kanervisto *et al.*, 2011). The analysis was adjusted for the effects of gender, age, smoking history and BMI.

Studies also provide some evidence for increased vulnerability to the effects of air pollution in deprived populations due to existing disease and risk factors for diseases related to lifestyle differences. For example, one study on 83 253 residents of Rome, Italy, found that people of higher socioeconomic status were exposed to higher levels of PM10 because they lived in more central city locations with high traffic volumes (Forastiere *et al.*, 2007). However, people of lower socioeconomic status, who generally lived on the outskirts of the city, were more likely to die from diseases associated with the effects of PM10, such as heart failure and chronic obstructive pulmonary disease, than the wealthier residents in the more-polluted city centre. The researchers concluded that PM had a stronger effect on deprived populations due to their greater susceptibility. This vulnerability was potentially associated with existing chronic diseases, as well as lifestyle factors, such as smoking, lack of physical activity and exposure at work. They also suggested that very wealthy residents spend less time in their official residences in the city centre, as they may have second homes elsewhere.

Ashtray by mikegi @Pixabay, 2014.

Similarly, Romieu *et al.* (2012) found that people of lower socioeconomic status living in cities across Latin America were more susceptible to the effects of PM10 and O3 than people of high socioeconomic status living in the same cities. In particular, they were more likely to die from COPD.

On the other hand, Huss *et al.* (2010) (**see also 3.2.1** for noise results) found no links between heart attack death, air pollution and socioeconomic factors in Switzerland. This suggests that associations between socioeconomic status and the health impacts of air pollution vary across different countries and geographic scales.

Limited evidence suggests that health inequalities and vulnerabilities could be perpetuated in future generations via epigenetic effects. Epigenetic changes to DNA are non-coding changes to its structure inside cells that determine which genes are active or become active. Some changes to gene 'expression' can be inherited and a review by Syed *et al.* (2013) cites research which suggests that the effects of air pollution in one generation could be passed on to the next, via changes to the expression of genes. For example, one exploratory study by Perera *et al.* (2009) suggested that increased exposure to PAH (polycyclic aromatic hydrocarbons) in a sample of New York women was associated with increased epigenetic changes to the asthma-related gene *ACSL3* and subsequent increases in reports of asthma symptoms among the women's children.

3.3 Multiple risk exposures

Within our environments, we face a multitude of different risks every day. Noise and air pollution are just two of many risks that may accumulate to result in greater impacts on socioeconomically disadvantaged populations. Evans and Kim (2010) reviewed studies on the links between socioeconomic status and health, suggesting that there is a linear relationship between socioeconomic status and **multiple risk exposures**. Risks do not accumulate dramatically in deprived populations; instead, it is thought that the risks increase quite gradually as socioeconomic status decreases. These multiple risk exposures provide a convincing explanation for health gradients. They include differences in exposure to housing-associated risks, pollutants and toxins, overcrowding, congestion, noise and neighbourhood quality

It seems likely that those who are exposed to high levels of transport-related air pollution would also be exposed to high levels of transport-related noise pollution. However, most studies assess noise and air pollution exposures separately and it is therefore difficult to understand the full extent of multiple transport-related air and noise pollution exposures, and any associated social inequalities.

One exception is Pelletier *et al.* (2013) (**see section 3.2.1**), which analysed links between socioeconomic factors and air traffic emissions (air and noise pollution) near French airports by integrating socioeconomic data from the French National Institute for Statistics and Economic Studies, geographical information system (GIS) data from noise

Cityscape with air pollution © Magdevski @iStock, 2016.

maps and air quality data from monitoring networks. The study concludes that *"the relationship between people that are over-exposed to noise and/or atmospheric pollution, and the level of social deprivation... cannot be coincidental"*.

Putrik *et al.* (2015) used self-reported data to analyse multiple environmental risk exposures in the municipality of Maastricht in the Netherlands. They claim their study is *"one of the few to have explored a nearly comprehensive list of perceived environment indicators studied in relation to both mental and general health"*. The list of risk exposures included aspects of the physical environment, such as traffic, green space, railway noise and availability of various public facilities, as well as aspects of the social environment, which include nuisances caused by people and feelings of safety.

The links between socioeconomic status and risk exposures are not straightforward, or consistent across all cities and regions. It is easy to equate living in congested, overcrowded areas with pollution and poor health, but the disadvantages must also be weighed against the potential health benefits. For example, densely populated areas may be noisier and have poorer air quality, but they may also provide more opportunities for meeting neighbours (Miles *et al.*, 2012). A lack of social networks may be a risk factor for mental health problems, such as depression. Equally, living in more affluent areas does not necessarily mean better access to quiet or green spaces or less traffic congestion, as shown in the case of Southampton, UK, by Battaner-Moro *et al.* (2010), where many affluent areas are near to motorways. However, wealthier people may, for example, be better able to mitigate exposure to pollution as they can afford noise insulation or escape from the city more regularly.

The bigger picture still suggests that social deprivation is linked to multiple increased exposures, but it is also important to recognise and account for the finer brush strokes which reveal contextual details.

3.4 Knowledge gaps in the evidence

This report finds some studies linking differences in socioeconomic status to differences in noise or air pollution exposure, and some studies linking differences in socioeconomic status to relevant health impacts. However, there are relatively few studies that attempt to link socioeconomic status to both exposure and impacts. Undoubtedly, this is because the indirect nature of the links makes it extremely challenging to show strong associations, but it does mean that the precise links remain unclear.

Moreover, every city, region and country faces different social circumstances and, therefore, the results of existing studies may be difficult to generalise or act upon. There is also little evidence for socioeconomic differences in exposure at regional, European or global levels. In addition, whilst there is an abundance of cross-sectional studies looking at exposures and impacts at specific time points, there is a lack of longitudinal research examining how exposures and impacts vary with time. Longitudinal research could focus on changes within the same regions over longer time periods, or on the same people exposed to different environments as they move.

Schmit and Lorant (2009) point to a general lack of research on socioeconomic aspects related to noise pollution. Meanwhile, considering noise and health research more widely, Lekaviciute *et al.* (2013) suggest that noise mapping methods need to be harmonised across different countries and that the level of detail in strategic noise maps required by the Environmental Noise Directive should be increased to help assess health effects. In addition, new methods are needed for measuring total noise exposure — from more than one source — and to separate the effects of exposures from different sources, such as traffic and industry (Lekaviciute *et al.*, 2013). The decibel measurements used in some studies do not differentiate between noise sources.

Noise measurements in scientific studies largely focus on transport sources, such as road traffic and aircraft, but often also include noise from other sources, such as neighbours. There are some regions and localities where lower socioeconomic status can be linked to higher noise levels, but links tend to be to outdoor noise at a local or building level, which does not account for differences in housing quality or use, or for differences in the noise levels away from home. No studies are identified by this report that assess noise exposure inside the home or for residents at individual levels. Whilst it may be assumed that buildings in more affluent areas are better insulated from noise, or that residents can better afford to mitigate the effects, this remains to be proven.

Finally, Hajat *et al.* (2015) suggest that further, more rigorous research is needed to understand the associations between air pollution and socioeconomic status in Europe. They emphasise that even when people of high socioeconomic status live in areas with high pollution concentrations, this does not necessarily mean that they are exposed to high levels of pollution, since they may have greater resources than deprived populations to protect themselves, for example, by paying for private transport and better housing.

Part 4. Reducing exposure to noise and air pollution

This section considers approaches to reducing exposure related to noise and air pollution relevant to urban design, planning and development. It also explores how we value the social costs of these health impacts..

Due to the significant negative health impacts of noise and air pollution on the population as a whole, policies addressing pollution and the aspects of living environments that expose us to pollution will benefit everyone. As Marmot et al. (2010) point out, while health inequalities do result from social inequalities, the focus must not be on deprived populations only.

Universal approaches that improve the quality of the living environment for all are of utmost importance. This would include taking measures to reduce the levels of and exposure by air pollution and noise. Moreover, measures to tackle the root causes of inequality — for instance, through providing fair education and employment (Marmot *et al.*, 2010) — may reduce the range of health inequalities, including those related to pollution. However, targeted measures may also be needed to reduce the vulnerability of socioeconomically deprived populations to the health impacts of polluted environments, and to ensure that they are not exposed to greater risks.

4.1 The influence of urban planning and development

How do urban design and form affect exposure to noise and air pollution? According to Harris and Pinoncély (2014), poorly designed developments, urban sprawl and poor quality housing are major causes of increased exposure to air pollution. This may also be true for noise pollution, especially given that the source — traffic — is very often the same. For example, urban sprawl and inadequate public transport systems may lead to large numbers of people commuting into city centres by car, increasing traffic-related air pollution and noise emissions. Poor governance and inadequacies in spatial planning may contribute to this

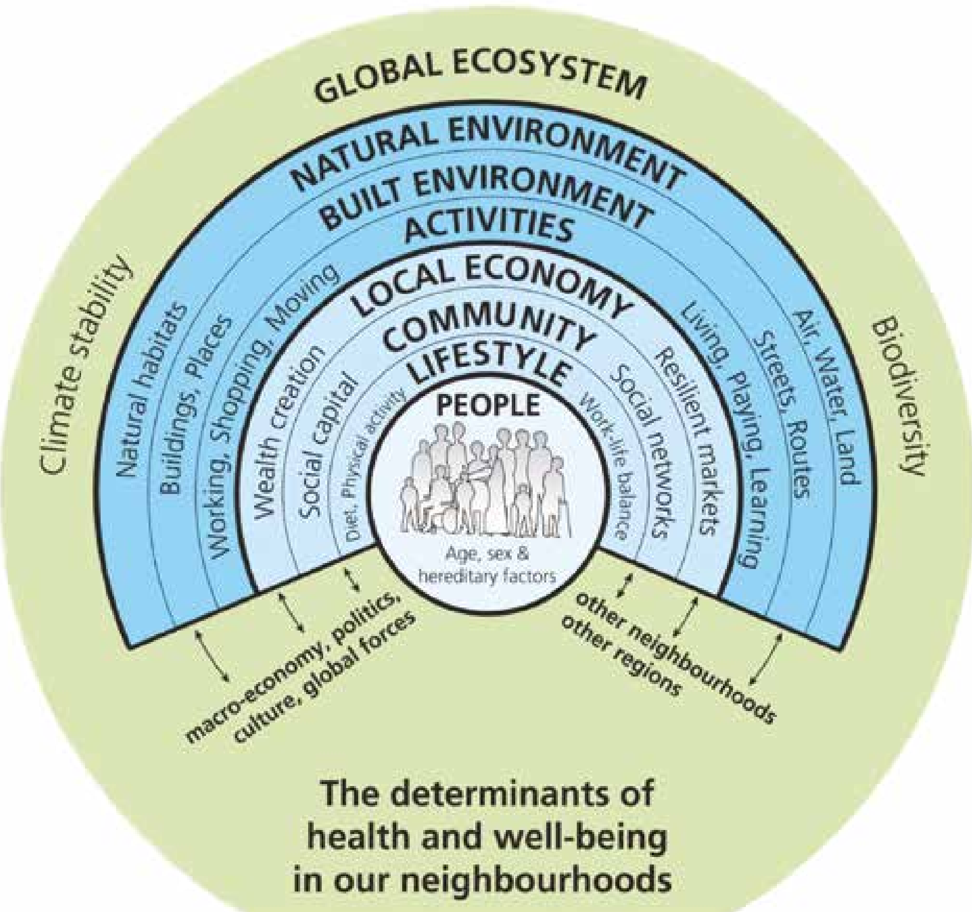


Figure 5: The determinants of health and wellbeing in settlements. Source: Barton and Grant (2006) [A health map for the local human habitat](), modified from Dahlgren and Whitehead (1992).

Smart fox by Lupus , Brussels, Belgium, Le.Mat CC BY-NC 2.0 @Flickr, 2012. Cropped.

situation. Unfortunately, the outcomes of poor planning, i.e. poorly designed infrastructure, are not easy to reverse.

How do planning and development affect the socioeconomic health gradient? **Figure 5** shows how health within urban settlements is determined by a complex range of factors, including broader social, political and economic factors, the structure of the built environment and factors related to people and their lifestyles, community and the local economy.

Knock-on effects occur between the different layers, which emphasises the role of planners in determining health (Barton and Grant, 2006). For example, a new road would affect people's travel behaviour ('Activities'), which would in turn affect air and noise pollution ('Natural Environment') and thereby health.

Individual building design and use also have an important impact on exposure levels, and are not often accounted for in studies on noise and air pollution. Orientation of bedroom windows may be a 'significant effect modifier' for heart disease linked to noise pollution from road traffic, according to Banerjee (2014). Stansfeld and Crombie (2011) suggest that, in addition to bedroom orientation, living room orientation, as well as window-opening habits, may also affect noise exposure. The potential influence of window-opening habits is a reminder that 'Lifestyle' (see **Figure 5**) may also play an important role in exposure.

4.2 Improving urban design, planning and development

Although noise and air pollution are addressed by separate Directives at a European level, there are obvious reasons for jointly addressing them at a local level as they often derive from the same sources, such as traffic and industry. Improvements in urban design, planning and development play an important role in reducing both noise and air pollution, and could also play a part in reducing related social and health inequalities. These improvements will need to incorporate both industrial and residential development decisions.

Within the EU, spatial planning is recognised as an important tool for integrating social and environmental policy agendas and could help translate between international/national-level and regional/local-level policy (Elbakidze *et al.*, 2015). However, planning systems differ substantially between European countries. Guidance from Environmental Protection UK and the Institute of Air Quality Management suggests that spatial planning could be better used to address air quality and to reduce exposure to air pollution (Moorcroft and Barrowcliffe, 2015). Also, the Joint Air Quality Initiative (JOAQUIN) has created a decision-support tool to help choose the best-fit measures to improve air quality traffic policies, to help address some of these differences.

One recent study (Rodriguez *et al.*, 2016) highlights the important influence of urban form on concentrations of air pollutants, showing that, for example, highly fragmented EU cities have higher concentrations of NO2 and PM. They argue for spatial planning that favours well-connected urban development, which could also reduce dependence on cars. Pelletier *et al.* (2013) suggest that a combination of noise and air pollution monitoring, and GIS mapping, could be used to help local authorities prioritise their actions to protect exposed populations. Harris and Pinoncély (2014) go further in arguing that policymakers need access to centralised spatial analysis maps.

Noise is often given little consideration in planning (Biamp Systems, n.d.). Schmit and Lorant (2009) highlight urban planning as a key component of public environmental policy in terms of reducing inequalities in noise exposure. Pope *et al.* (2014) developed an urban design toolkit for future cities, outlining 23 'tools' for improving urban soundscapes. A number of these relate to traffic and could therefore also improve air quality. They include zoning that places residential homes close to city centres and places of work — potentially reducing traffic — but away from industrial noise sources, as well as improving public transport links in areas of high population density. Clearly, some of these measures are already being adopted to some extent, while others, such as absorbent building facades, are very rarely used (Pope, 2015).

Within a neighbourhood or city, levels of noise and air pollution are influenced by the balance of car use compared with more sustainable forms of transport. Neighbourhood form — including density of housing, mix of different land uses and availability of facilities — may also, in turn, play a part in determining levels of car use (Miles *et al.*, 2012). However, the relationship between neighbourhood form and health is more complex than just its influence on exposure to environmental pollutants. For example, some sustainable building ratings systems, such as Leadership in Energy & Environmental Design (LEED)[11], promote high-density living based on the assumptions that it will limit sprawl, use existing infrastructure and increase the likelihood of social and community interactions, which would be beneficial for health. However, high-density housing may also increase noise from neighbourhood sources.

Some aspects of the built environment cannot be easily or quickly changed in established cities and thus options for reducing pollution levels within and around the existing infrastructure may be preferable. Sustainable, affordable public transport, and safe cycling and walking routes, alongside strict vehicle emissions standards, will be key to improving air quality and reducing traffic noise. In the meantime, intelligent route planning may help citizens to avoid the most polluted routes. For example, one recent study describes a Google Maps-based app designed to help Montreal-based cyclists choose routes with lower

Dragonfly, Sevilla, Spain, Graffiti along canal by VC Baked Beans CC BY-NC 2.0 @Flickr 2012.

11. *www.usgbc.org/leed*

exposure levels (Hatzopoulou *et al.*, 2013). Several EU cities, including Madrid, Dublin and Paris, already have plans to pedestrianise central areas (Jaffe, 2015). Low emission zones, traffic calming measures and restrictions on fuel-burning may help to alleviate air quality problems in the worst-affected areas, according to Cartier *et al.* (2015). Roadside vegetation can also help to disperse air pollutants and improve air quality near to roads, although the characteristics of individual sites need to be carefully accounted for in the design of vegetation barriers (Tong *et al.*, 2016).

Meanwhile, for noise pollution, the possibilities for retrofitting existing buildings to reduce noise could also be explored further. Sound absorbent surfaces are commonly used in hospitals and one trial in a school in Essex, UK, suggests noise reduction approaches could improve concentration levels (Biamp Systems, n.d.). Building renovations may also need to consider safe heating and cooking options in view of a potential increase in pollution from burning wood — a cheap fuel — as fossil fuel prices continue to rise (Fuller *et al.*, 2014).

Contact with nature and access to parks is widely believed to have mental health benefits. Green and quiet spaces may provide opportunities for stress relief and recovery from mental fatigue (Miles *et al.*, 2012). However, some people may enjoy spending time in more lively, bustling environments, such as busy city centres. Andringa and Lanser (2013) emphasise the benefits of exposure to a range of different types of environment. Marmot *et al.* (2010) advise that access to high-quality green spaces should be improved across the social gradient, ensuring resources are allocated proportionately to deprivation levels. Despite the need to supply affordable new housing, green spaces must be protected, particularly within deprived neighbourhoods. New green spaces should be targeted at more highly polluted areas (Cartier *et al.*, 2015).

As well as policy interventions, evaluation tools for assessing the impacts of interventions on health inequalities are needed. Cartier *et al.* (2015), for example, recently published a study outlining a tool designed for non-experts to use in evaluating the health and equity impacts of urban air quality interventions. They describe how the tool helps decision-makers identify relevant questions for evaluating their specific interventions and how it may, in turn, lead to better-designed interventions (**see Box 1**).

In addition to what policymakers can do, Pratt *et al.* (2015) recommend actions that individuals can take to reduce their personal exposure to air pollution, for example, choosing to walk or cycle along less polluted routes or considering traffic impacts on housing choices. The US National Resources Defense Council suggests that citizens should take "*any steps* [they] *can*" to ensure that new schools and housing developments are not situated near busy roads or industrial areas where exposure to noise and air pollution is likely to be high (NRDC, 2015). However, these types of recommendations can be seen to encourage a reactionary, rather than early-engagement, approach to involving citizens in local planning. As well as more participatory approaches, local communities may also benefit from better integration of planning policy with local environmental, health and transport policy (Marmot *et al.*, 2010).

4.3 Policies to address multiple risk exposures

Noise and air pollution are part of a wider spectrum of risks and need to be addressed as such. Kjellstrom *et al.* (2007) promote a view of the 'health-supporting physical living environment' as a dimension of poverty, whilst Putrik *et al.* (2015) call for local policymakers to recognise that health inequalities can only be reduced by designing policies that target a whole range of social determinants of health, including environmental and individual factors. There may be a need for greater awareness and recognition within evidence-based policymaking of the fact that differences in environmental exposures — including to noise and air pollution — contribute to and exacerbate health inequalities (Pratt *et al.*, 2015).

Marmot *et al.* (2010) and Hutton and Chan (2013) emphasise the importance of looking beyond economic values of development and growth, and considering alternative indicators that incorporate health and wellbeing. More specifically, Battaner-Moro *et al.* (2010) suggest that measurements of access to quiet spaces should be developed as indicators of deprivation in indices of socioeconomic status that incorporate both wealth and health.

People of low socioeconomic status living in low-quality environments are exposed to increased risks from multiple sources, with noise and air pollution contributing to the overall toll on their health. Therefore, policies designed to tackle a broader spectrum of socioeconomic and health inequalities could have co-benefits (Marmot *et al.*, 2010). For example, encouraging more active travel (walking and cycling) could reduce GHG emissions and reliance on non-renewable fuels, in addition to reducing inequalities in exposure to air and noise pollution. Meanwhile, incentives could be provided for using less polluting, low-carbon transport technologies, such as electric and hybrid vehicles, although they may still be less affordable to the socioeconomic groups most affected by transport pollution (Pratt *et al.*, 2015). Improving access to green space could provide opportunities for physical activity, as well as quiet spaces for relief from noise pollution.

Improving access to green space could provide opportunities for physical activity, as well as quiet spaces for relief from noise pollution.

According to the WHO, inter-sectoral policymaking is crucial to progress on the social determinants of health (WHO, 2010a). The EU follows a Health in all Policies (HIAP) approach[12] to policymaking that emphasises the importance of all public policies and decisions in influencing health impacts (Leppo *et al.*, 2013). The HIAP approach recognises that it is not just 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.

4.4 How to value the social cost of noise and air pollution

Placing a value on the social cost of pollution helps us to understand its full impact, compare it with other social problems and appraise the potential benefits of policy measures designed to reduce its impact. The European Commission estimated the social cost of road traffic noise in the EU — including death and disease — at approximately €40 billion per year (European Commission, 2011). An estimated 90% of this cost is related to passenger cars and goods vehicles. Meanwhile, Yim *et al.* (2015) put the cost of deaths in Europe related to PM2.5 and O3 exposure due to aircraft alone at $9–10 billion (€8–9 billion) per year. The overall health-related costs of air pollution, including €15 billion due to lost workdays, are estimated at between €330 and €940 billion for the EU (European Commission, 2013). The total cost of noise and air pollution in the EU may therefore be approaching €1 trillion. For comparison, the social cost of alcohol in the EU, including all alcohol-related disease, effects on employment and productivity and crime, is estimated to be €50-120 billion (Rehm *et al.*, 2012) and smoking at €544 billion (Jarvis, 2012).

Social costs can be calculated by a number of methods. Some of these distinguish solely between life and death, while others distinguish between better and worse states of health (Australian Government, 2008). The value of a statistical life (VSL) is based on the willingness of individuals or society to pay for avoided death and is also used in health decision-making to compare the effectiveness of life-saving interventions (Hammit, 2007). A potentially more useful measure is the value of a statistical life year (VSLY), which places a value on one year of human life; this is often the more practical measure for decision-making about health interventions, as most diseases are not immediately fatal (Australian Government, 2008). One problem is that richer nations generally place a higher value on statistical human life and thus it is difficult to compare impacts between countries.

For estimates based on health and wellbeing, rather than avoided deaths, researchers and governments tend to use Quality Adjusted Life Years (QALYs) or Disability Adjusted Life Years (DALYs). Whilst the cost of deaths related to air pollution exposure might be better valued by the VSL approach — as in Yim *et al.*'s 2015 study — the cost of annoyance or sleep loss related to noise pollution might be more appropriately valued using DALYs. The European Environment Agency (EEA) recommends the use of DALYs in its Good Practice Guide on Noise Exposure and Potential Health Effects (2010). As the document suggests, it may be difficult to produce accurate estimates, not least because values are based on subjective weightings for different health conditions. Death is weighted at 1.00, whilst heart disease might, for example, be given a weight of 0.35 compared with 0.07 for sleep disturbance. However, these kinds of valuations do at least provide scope for ranking different policy interventions and different environmental stressors.

Based on DALY valuations, the EEA's rankings suggest that the effects of environmental noise cause greater losses in health and wellbeing than ozone and the short-term effects of PM, but that the long-term effects of PM take a much greater toll. According to these rankings, particulates cause a greater loss of health and wellbeing than even traffic accidents.

Socioeconomic differences mean that not everyone is willing or able to pay the same amount to save a life, or improve their quality of life (Australian Government, 2008). The purpose of public health systems is to fill the gap, ensuring that everyone is able to access the same standard of care (Whitehead and Dahlgren, 2007).

12. http://ec.europa.eu/health/health_policies/policy/index_en.htm

Part 5: Summary

Air pollution and noise pollution have a negative impact on all sectors of society, rich and poor. However, it seems likely that some groups of society are more affected than others. These health inequalities may arise as a result of increased exposure to pollution, increased sensitivities, increased vulnerabilities, or a combination of all three.

Some studies suggest that people in deprived areas are exposed to higher levels of air and noise pollution. These studies are largely focused on specific regions or cities, and on traffic as a pollution source. Other studies provide counter-examples of high-income groups being exposed to higher levels of pollution.

However, lower socioeconomic status is associated with poorer health in a more general sense. This potentially means that deprived populations are more vulnerable to the effects of noise and air pollution, for instance, through existing long-term health conditions. Health research already shows that people of low socioeconomic status 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 could be exacerbated by exposure.

Studies have shown increased health effects or deaths linked to noise and air pollution in deprived populations compared with wealthier populations, although, again, studies tend to be carried out in specific regions or cities, with a few exceptions at national levels. Thus, while there is not yet conclusive evidence for a 'double burden' of increased exposure and increased vulnerability in all deprived areas of Europe, it is likely that deprived populations living in areas that are exposed to high levels of pollution will experience the worst effects.

Noise and air pollution contribute to a wide range of factors influencing the health of populations, which include aspects of the living environment to individual lifestyle choices. Although their specific contributions may be difficult to measure, 'multiple risk exposures' are thought to accumulate in deprived populations in a fairly linear fashion. Lower socioeconomic groups thus face a greater risk of poor health for a variety of reasons. Addressing this socioeconomic–health gradient is complex since it requires all sectors of society to have access to the same resources and standards of living.

Further studies directly measuring both exposure and health impacts are needed to explore associations between socioeconomic status and noise and air pollution in Europe. Longitudinal studies — involving multiple rounds of data collection — are required to understand the long-term consequences of exposure to air and noise pollution. Also needed are studies investigating the effects of moving between areas with different socioeconomic characteristics and with different levels of exposure to pollution.

The existing evidence on this topic should be treated with some caution due to a lack of consistency in study methods. It is currently difficult to compare and contrast results between studies, or to draw wider conclusions about the role of socioeconomic status in exposure to noise and air pollution and resulting health impacts.

Malmö, Sweden. Taken during the 2014 assessment visit of Malmo for The European City of the Year award. By The Academy of Urbanism, CC BY-NC-ND 2.0 @Flickr, 2012.

Reducing noise and air pollution will have a positive impact on health for all. Promoting and adopting more sustainable forms of transport could, for instance, reduce both noise and air pollution from traffic, whilst intelligent use of spatial planning tools and data could separate living, working and commuting areas from polluted areas. More stringent limits on both air and noise emissions, including combined emissions, would also reduce health impacts for everyone. In addition to universal measures, targeted measures designed to reduce exposure particularly in deprived populations will help to ensure that the poorest in society do not suffer the greatest health consequences related to noise and air pollution.

References

Andringa, T. C., & Lanser, J. J. L. (2013). How pleasant sounds promote and annoying sounds impede health: a cognitive approach. *International Journal of Environmental Research and Public Health.* 10(4): 1439–61. DOI:10.3390/ijerph10041439.

Arber, S., Bote, M. and Meadows, R. (2009). Gender and socio-economic pattering of self-reported sleep problems in Britain. *Social Science & Medicine.* 68(2): 281-289. DOI: 10.1016/j.socscimed.2008.10.016.

Australian Government. (2008). *The health of nations: the value of a statistical life.* Canberra: Australian Safety and Compensation Council. Available: http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/330/TheHealthOfNations_Value_StatisticalLife_2008_PDF.pdf

Banerjee, D., Das, P.P., & Foujdar, A. (2014). Association between road traffic noise and prevalence of coronary heart disease. *Environmental Monitoring and Assessment.* 186(5): 2885–2893. DOI:10.1007/s10661-013-3587-3.

Barton, H. and Grant, M. (2006). A health map for the local human habitat. *The Journal for the Royal Society for the Promotion of Health.* 126(6): 252-253. DOI: 10.1177/1466424006070466.

Battaner-Moro, J., Barlow, C., & Wright, P. (2010). Social Deprivation And Accessibility To Quiet Areas In Southampton. In: *Noise in the Built Environment.* 29-30 April 2010, Ghent, Belgium.

Biamp Systems. (n.d.) *Building in Sound: Biamp Systems White Paper.* Biamp Systems, 1-17.

Bilger, M. and Carrieri, V. (2013). Health in the cities: When the neighbourhood matters more than income. *Journal of Health Economics.* 32(1): 1-11. DOI: 10.1016/j.jhealeco.2012.09.010.

Brook, R. D.; Franklin, B.; Cascio, W; Hong, Y; Howard, G; Lipsett, M; Luepker, R; Mittleman, M; Samet, J; Smith Jr, S. C.; Tager, I (2004) AHA Scientific Statement: Air Pollution and Cardiovascular Disease. *Circulation* 109: 2655–2671. DOI: 10.1161/01.CIR.0000128587.30041.C8.

Cartier, Y., Benmarhnia, T., Brousselle, A. (2015). Tool for assessing health and equity impacts of interventions modifying air quality in urban environments. *Evaluation and Program Planning.* 53: 1-9. DOI:10.1016/j.evalprogplan.2015.07.004.

Civil Aviation Authority. (2014). *Aircraft noise, sleep disturbance and health effects.* Civil Aviation Authority, London, June 2014. 1-17. Available from: http://www.caa.co.uk/docs/33/CAP 1164_Aircraft noise_and_health.pdf

CSDH. (2008). *Closing the gap in a generation: healthy equity through action on the social determinants of health.* Final report of the Commission on Social Determinants of Health. Geneva, World Health Organization. Available: http://apps.who.int/iris/bitstream/10665/43943/1/9789241563703_eng.pdf

Dahlgren, G. and Whitehead, M. (1992). *Policies and strategies to promote equity in health.* Copenhagen: WHO Regional Office for Europe.

Dale, L.M., Goudreau, S., Perron, S., Ragettli, M.S., Hatzopoulou, M., Smargiassi, A. (2015) Socioeconomic status and environmental noise exposure in Montreal, Canada. *BMC Public Health.* 15(1): 205. DOI: 10.1186/s12889-015-1571-2.

Dalstra, J.A.A., Kunst, A.E., Borrell, C., Breeze, E., Cambois, E., Costa, G., Geurts, J.J.M., Lahelma, E, Van Oyen, H., Rasmussen, N.K., Regidor, E., Spadea, T. and Mackenbach, J.P. (2005) *Socioeconomic differences in the prevalence of common chronic diseases: an overview of eight European countries. International Journal of Epidemiology.* 34(2): 316–326. DOI: 10.1093/ije/dyh386.

Deguen S, Petit C, Delbarre A, Kihal W, Padilla C, Benmarhnia T, *et al.* (2015) Neighbourhood Characteristics and Long-Term Air Pollution Levels Modify the Association between the Short-Term Nitrogen Dioxide Concentrations and All-Cause Mortality in Paris. PLoS ONE 10(7): e0131463. doi:10.1371/journal.pone.0131463

Eagan, T.M.; Gulsvik, A.; Eide, G.E. and Bakke, P.S. (2004) The effect of educational level on the incidence of asthma and respiratory symptoms. *Respiratory Medicine* 98(8): 730–6.

EEA. (2010). *Good practice guide on noise exposure and potential health effects. EEA Technical Report,* 11/2010. Luxembourg: Office for Official Publications of the European Union. Available: http://www.eea.europa.eu/publications/good-practice-guide-on-noise

EEA. (2014a) *Noise in Europe 2014. European Environment Agency, Report 10/2014.* Luxembourg: Publications Office of the European Union. Available: http://www.eea.europa.eu/publications/noise-in-europe-2014/at_download/file

EEA. (2014b). *Air quality in Europe — 2014 report. European Environment Agency, Report 5/2014.* Luxembourg: Publications Office of the European Union. Available: http://www.eea.europa.eu/publications/air-quality-in-europe-2014

EEA. (2015a). *Air quality in Europe — 2015 report. European Environment Agency, Report 5/2015.* Luxembourg: Publications Office of the European Union. Available: http://www.eea.europa.eu/publications/air-quality-in-europe-2015

EEA. (2015b). *Contribution of the transport sector to total emissions of the main air pollutants.* Available from: http://www.eea.europa.eu/data-and-maps/daviz/contribution-of-the-transport-sector-2

Elbakidze, M., Dawson, L., Andersson, K., Axelsson, R., Angelstam, P., Stjernquist, I., Teitelbaum, S., Schlyter, P. and Thellbro, C. (2015). Is spatial planning a collaborative learning process? A case study from a rural-urban gradient in Sweden. *Land Use Policy.* 48:270-285. DOI: 10.1016/j.landusepol.2015.05.001.

European Commission. (2011). *Report from the Commission to the European Parliament and the Council On the implementation of the Environmental Noise Directive in accordance with Article 11 of Directive 2002/49/EC.* Brussels: European Commission. Available: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0321

European Commission. (2013). *Commission staff working document, Impact Assessment — SWD (2013)531.* Brussels: European Commission. Available: http://ec.europa.eu/governance/impact/ia_carried_out/docs/ia_2013/swd_2013_0531_en.pdf

Evans, G. W., & Kim, P. (2010). Multiple risk exposure as a potential explanatory mechanism for the socioeconomic status-health gradient. *Annals of the New York Academy of Sciences.* 1186:174–189. DOI:10.1111/j.1749-6632.2009.05336.x.

Fang, S.C., Schwartz, J., Yang, M., Yaggi, H.K., Bliwise, D.L. & Araujo, A. B. (2015). Traffic-related air pollution and sleep in the Boston Area Community Health Survey. *Journal of Exposure Science & Environmental Epidemiology*. 25(5): 451-456. DOI:10.1038/jes.2014.47.

Fecht, D., Fischer, P., Fortunato, L., Hoek, G., De Hoogh, K., Marra, M., Kruize, H., Vienneau, D., Beelen R. and Hansell, A. (2015). Associations between air pollution and socioeconomic characteristics, ethnicity and age profile of neighbourhoods in England and the Netherlands. *Environmental Pollution.* 198: 201-210. DOI: 10.1016/j.envpol.2014.12.014.

Floud, S., Blangiardo, M., Clark, C., de Hoogh, K., Babisch, W., Houthuijs, D., Hansell, A. L. (2013). Exposure to aircraft and road traffic noise and associations with heart disease and stroke in six European countries: a cross-sectional study. *Environmental Health.* 12: 89. DOI: 10.1186/1476-069X-12-89.

Forastiere, F., Stafoggia, M., Tasco, C., Picciotto, Agabiti, N., Cesaroni, G., Perucci, C.A. (2007). Socioeconomic status, particulate air pollution, and daily mortality: Differential exposure or differential susceptibility. *American Journal of Industrial Medicine.* 50: 208-216. DOI: 10.1002/ajim.20368.

Fuller, G.W., Tremper, A.H., Baker, T.D., Yttri, K.E., Butterfield, D. (2014). Contribution of wood burning to PM10 in London. *Atmospheric Environment.* 87: 87-94. DOI:10.1016/j.atmosenv.2013.12.037.

Fyhri, A. and Klaeboe, R. (2006). Direct, indirect influences of income on road traffic noise annoyance. *Journal of Environmental Psychology*. 26: 27-37. DOI:10.1016/j.jenvp.2006.04.001.

Givens, M.L., Malecki, K.C., Peppard, P.E., Palta, M., Said, A., Engelman, C.D., Walsh, M.C. & Nieto, F.J. (2015) Shiftwork, sleep habits, and metabolic disparities: results from the Survey of the Health of Wisconsin. *Sleep Health.* 1(2): 115–120. DOI:10.1016/j.sleh.2015.04.014.

Goodman, A., Wilkinson, P., Stafford, M. and Tonne, C. (2011). Characterising socio-economic inequalities in exposure to air pollution: A comparison of socio-economic markers and scales of measurement. *Health and Place.* 17: 767-774. DOI:10.1016/j.healthplace.2011.02.002.

Gray, S.C., Edwards, S.E. and Miranda, M.L. (2013). Race, socioeconomic status, and air pollution exposure in North Carolina. *Environmental Research.* 126: 152-158. DOI:10.1016/j.envres.2013.06.005.

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the ecology of cities. *Science.* 319(5864): 756–760. DOI:10.1126/science.1150195.

Hajat, A., Hsia, C. and O'Neill, S. (2015). *Socioeconomic disparities and air pollution exposure: A global review.* Current Environmental Health Reports 2:440–450. DOI:10.1007/s40572-015-0069-5

Hammitt, J.K. (2007). Valuing Changes in Mortality Risk: Lives Saved versus Life Years Saved. *Review of Environmental Economics and Policy.* 1(2): 228-240. DOI: 10.1093/reep/rem015.

Hancox, R.J.; Milne, B.J.; Taylor, D.R.; Greene, J.M.; Cowan, J.O.; Flannery, E.M.; Herbison, G.P.; McLachlan, C.R.; Poulton, R. and Sears, M.R. (2004) Relationship between socioeconomic status and asthma: a longitudinal cohort study. *Thorax.* 59: 376–380 DOI:10.1136/thx.2003.010363

Hansell, A.L., Blangiardo, M., Fortunato, L., Floud, S., de Hoogh, K., Fecht, D., Ghosh, R.E., Laszlo, H.E., Pearson, C., Beale, L., Beevers, S., Gulliver, J., Best, N., Richardson, S., Elliott, P. (2013). Aircraft noise and cardiovascular disease near Heathrow airport in London: small area study. *BMJ.* 347: f5432. DOI:10.1136/bmj.f5432.

Harris, M. & Pinoncély, V. (2014). *Thinking Spatially: Why Places Need to be at the Heart of Policy-Making in the Twenty-First Century.* London: Royal Town Planning Institute. Available: http://www.rtpi.org.uk/media/1004403/rtpi_thinking_spatially.pdf

Hatzopoulou, M., Weichenthal, S., Barreau, G., Goldberg, M., Farrell, W., Crouse, D. and Ross, N. (2013). A web-based route planning tool to reduce cyclists' exposures to traffic pollution: A case study in Montreal, Canada. *Environmental Research.* 123:58-61. DOI:10.1016/j.envres.2013.03.004.

Hedlund, U., Eriksson, K. and Rönmark, E. (2006) Socio-economic status is related to incidence of asthma and respiratory symptoms in adults. *European Respiratory Journal.* 28(2):303–10. DOI: 10.1183/09031936.06.00108105.

Henschel, S. and Chan, G. (2013). *Health risks of air pollution in Europe — HRAPIE project: New emerging risks to health from air pollution — results from the survey of experts.* Copenhagen: WHO Regional Office for Europe. http://www.euro.who.int/__data/assets/pdf_file/0017/234026/e96933.pdf?ua=1

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. *Gesundheitswesen*. 65(6): 393–401. DOI: 10.1055/s-2003-40308.

Huss, A., Spoerri, A., Egger, M. and Röösli, M. (2010). Aircraft noise, air pollution, and mortality from myocardial infarction. *Epidemiology*. 21(6): 829-836. DOI: 10.1097/EDE.0b013e3181f4e634.

Hutton, G., & Chan, G. (2013). *Environmental Health and Economics: Strategic Framework and Implementation Plan 2013-2017*, Bonn, Germany. Copenhagen, WHO Regional Office for Europe. Available: www.euro.who.int/en/health-topics/environment-and-health/health-impact-assessment/publications/2013/environmental-health-and-economics-strategic-framework-and-implementation-plan-20132017

Jaffe, E. (2015). 6 big European cities with plans to go car-free. *City Lab*, 20th October. Available: http://www.citylab.com/cityfixer/2015/10/6-european-cities-with-plans-to-go-car-free/411439 [Accessed: 26th October 2015].

Jarvis, A. (2012). *A study on the liability and health costs of smoking DG SANCO (2008/C6/046)*. London: GHK/University of Exeter/Public Health Advocacy Institute. Available: http://ec.europa.eu/health/tobacco/docs/tobacco_liability_final_en.pdf

Kamphuis, C. B. M., Turrell, G., Giskes, K., Mackenbach, J. P., & Van Lenthe, F. J. (2013). Life course socioeconomic conditions, adulthood risk factors and cardiovascular mortality among men and women: A 17-year follow up of the GLOBE study. *International Journal of Cardiology*. 168(3): 2207–2213. DOI:10.1016/j.ijcard.2013.01.219.

Kanervisto, M.; Vasankari, T.; Laitinen, T.; Heliövaara, M.; Jousilahti, P. and Saarelainen, S. (2011) Low socioeconomic st6atus is associated with chronic obstructive airway diseases. *Respiratory Medicine* 105(8): 1140–1146.

Kelly, F. J. (2014) Influence of air pollution on respiratory disease. *EMJ Respiratory*. 2014 2: 96-103.

Kjellstrom, T., Friel, S., Dixon, J., Corvalan, C., Rehfuess, E., Campbell-Lendrum, D., Bartram, J. (2007). Urban environmental health hazards and health equity. *Journal of Urban Health*. 84(SUPPL. 1), 86–97. DOI:10.1007/s11524-007-9171-9.

Kohlhuber, M., Mielck, A., Weiland, S.K. and Bolte, G. (2006). Social inequality in perceived environmental exposures in relation to housing conditions in Germany. *Environmental Research*. 101(2): 246-255. DOI:10.1016/j.envres.2005.09.008.

Landry, G.J., Best, J.R., Liu-Ambrose, T.L. (2015). Measuring sleep quality in older adults: a comparison using subjective and objective methods. *Frontiers in Ageing Neuroscience*. 7(166). DOI:10.3389/fnagi.2015.00166.

Lederbogen, F., Kirsch, P., Haddad, L., Streit, F., Tost, H., Schuch, P., Wüst, S., Pruessner, J.C., Rietschel, M., Deuschle, M. & Meyer-Lindenberg, A. (2011). City living and urban upbringing affect neural social stress processing in humans. *Nature*. 474(7352) : 498–501. DOI:10.1038/nature10190.

Lee, B.-J., Kim, B., & Lee, K. (2014). Air pollution exposure and cardiovascular disease. *Toxicological Research*. 30(2): 71–5. DOI:10.5487/TR.2014.30.2.071.

Lekaviciute, J., Kephalopoulos, S., Stansfeld, S., & Clark, C. (Eds.) (2013). Final Report ENNAH — *European Network on Noise and Health*. Luxembourg: Publications Office of the European Union. DOI:10.2788/83694. Available: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC77642/jrc%2077642_ennah-final-report_online_19_3_2013.pdf

Lelieveld, J., Evans, J.S., Fnais, M., Giannadaki, D. & Pozzer, A. (2015) The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature*. 525(7569): 367–371. DOI:10.1038/nature15371.

Leppo, K., Olila, E., Peña, S., Wismar, M., and Cook, S. (Eds.) (2013). Health in all policies: *Seizing opportunities, implementing policies*. Helsinki: Ministry of Social Affairs and Health. Available: http://www.euro.who.int/__data/assets/pdf_file/0007/188809/Health-in-All-Policies-final.pdf

Mackay J., Mensah G.A. (2004). *The Atlas of Heart Disease and Stroke*. Geneva: World Health Organization. Available: http://www.who.int/cardiovascular_diseases/resources/atlas/en/

Marmot, M., Allen, J., Goldblatt, P., Boyce, T., McNeish, D., Grady, M., Geddes. I. (2010). *Fair Society, Healthy Lives. Strategic Review of Health Inequalities in England Post-2010*. London: The Marmot Review. http://www.instituteofhealthequity.org/projects/fair-society-healthy-lives-the-marmot-review

Maté T, Guaita R, Pichiule M. (2010) Short-term effect of fine particulate matter (PM2.5) on daily mortality due to diseases of the circulatory system in Madrid (Spain). *Science of the Total Environment* 408: 5750–5757.

McLennan, D., Barnes, H., Noble, M., Davies, J., Garratt, E., Dibben, C. (2011). *The English Indices of Deprivation 2010. Neighbourhoods Statistical Release*. London: Department for Communities and Local Government. Available: http://www.communities.gov.uk/publications/corporate/statistics/indices2010technicalreport

Miles, R., Coutts, C., & Mohamadi, A. (2012). Neighborhood urban form, social environment, and depression. *Journal of Urban Health*. 89(1): 1–18. DOI:10.1007/s11524-011-9621-2.

Moorcroft, S. and Barrowcliffe, R. (2015). *Land-use planning & development control: Planning for air quality*. London: Institute of Air Quality Management. Available: http://www.iaqm.co.uk/text/guidance/iaqm-planning-development.pdf

Mosca, I., Bhuachalla, B.N., Kenny, R.A. (2013). Explaining significant differences in subjective and objective measures of cardiovascular health: evidence for the socioeconomic gradient in a population-based study. *BioMed Central Cardiovascular Disorders*. 13(64). DOI:10.1186/1471-2261-13-64.

NRDC. (2015). *Asthma and air pollution*. Natural Resources Defense Council. Available: http://www.nrdc.org/health/effects/fasthma.asp [Accessed: 2nd July 2015].

OECD. (2014). *The Cost of Air Pollution: Health Impacts of Road Transport*. Paris: OECD Publishing. Available: http://www.oecd.org/env/the-cost-of-air-pollution-9789264210448-en.htm

Payne, G. and Payne, J. (2004). *Longitudinal and cross-sectional studies*. In The SAGE Key Concepts series: Key concepts in social research. (pp. 144-149). London, England: SAGE Publications.

Pearce, J., Tisch, C., Mitchell, R., Shortt, N. and Richardson, E. (2013). *Geographical and Social Inequalities in Particulate Matter (PM10) and Ozone Air Pollution in the EU: 2006 to 2010*. Edinburgh and Glasgow: Centre for Research on Environment, Society and Health.

Pelletier, A., Ribeiro, C., Mietlicki, F., Dugay, F., Kauffmann, a, Lalloué, B., Girard, D. (2013). SURVOL part 3 : Environmental pollution (air, noise) exposure and social deprivation around the major Ile-de-France airports, 1–10. In: *42nd International Congress and Exposition on Noise Control Engineering 2013 (INTER-NOISE 2013)*. Innsbruck, 15-18 September 2013. Vienna: Austrian Noise Abatement Association (OAL).

Perera F., Tang, W-y, Herbstman, J., Tang, D., Levin, L., Miller, R., Ho, S.M. (2009) Relation of DNA Methylation of 5'-CpG Island of ACSL3 to Transplacental Exposure to Airborne Polycyclic Aromatic Hydrocarbons and Childhood Asthma. *PLoS ONE*. 4(2): e4488. DOI:10.1371/journal.pone.0004488.

Pope, D., Lawrence, A., Ekici, I. (2014) The Future Sound of Cities. In: Invisible Places, Sounding Cities. 18–20 July 2014, Viseu, Portugal.

Pope, D. (2015). Personal Communication. 21st September 2015.

Power, M.C., Kioumourtzoglou, M.-A., Hart, J.E., Okereke, O.I., Laden, F., & Weisskopf, M.G. (2015). The relation between past exposure to fine particulate air pollution and prevalent anxiety: observational cohort study. *BMJ*. 350(mar23 11): h1111–h1111. DOI:10.1136/bmj.h1111.

Poyser, M.A.; Nelson, H.; Ehrlich, R.I.; Bateman, E.D.; Parnell, S.; Puterman, A. and Weinberg, E. (2002) Socioeconomic deprivation and asthma prevalence and severity in young adolescents. *The European Respiratory Journal*. 19(5): 892–8. .

Pratt, G.C., Vadali, M.L., Kvale, D.L. and Ellickson, K.M. (2015). Traffic, air pollution, minority and socio-economic status: addressing inequities in exposure and risk. *International Journal of Environmental Research and Public Health*. 12: 5355-5375. DOI:10.3390/ijerph120505355.

PRB. (2015). *Human Population: Urbanization*. Population Reference Bureau. Available: http://www.prb.org/Publications/Lesson-Plans/HumanPopulation/Urbanization.aspx

Prescott, E. and Vesbo, J. (1999) Socioeconomic status and chronic obstructive pulmonary disease. *Thorax*. 54: 737–741. DOI:10.1136/thx.54.8.737

Propper, C. and Rigg, J. (2006) *Understanding socio-economic inequalities in childhood respiratory health*. Centre for Analysis of Social Exclusion, LSE: London. Available at: http://eprints.lse.ac.uk/6238/1/Understanding_socio-economic_inequalities_in_childhood_respiratory_health.pdf

Putrik, P., de Vries, N. K., Mujakovic, S., van Amelsvoort, L., Kant, I.J., Kunst, A.E. and Jansen, M. (2015). Living Environment Matters: Relationships Between Neighborhood Characteristics and Health of the Residents in a Dutch Municipality. *Journal of Community Health*, 47–56. DOI:10.1007/s10900-014-9894-y.

Rehm, J., Shield, K.D, Rehm, M.X., Gmel, G. and Frick, U. (2012). *Alcohol consumption, alcohol dependence and attributable burden of disease in Europe: Potential gains from effective interventions for alcohol dependence*. Toronto: Centre for Addiction and Mental Health. Available: http://amphoraproject.net/w2box/data/AMPHORA%20Reports/CAMH_Alcohol_Report_Europe_2012.pdf

Richardson, E. A.; Pearce, J.; Tunstall, H.; Mitchell, R. and Shortt, N. K. (2013) Particulate air pollution and health inequalities: a Europe-wide ecological analysis. *International Journal of Health Geographics*. 12: 34. DOI: 10.1186/1476-072X-12-34

Robotham, D., Chakkalackal, L. and Cyhlorova, E. (2011). *Sleep Matters: The Impact of Sleep on Health and Wellbeing*. London: Mental Health Foundation. Available: https://www.mentalhealth.org.uk/publications/sleep-report

Rodriquez, M.C., Dupont-Courtade, L. and Oueslati, W. (2016). Air pollution and urban structure linkages: Evidence from European cities. *Renewable and Sustainable Energy Reviews*. 53: 1-9. DOI: 10.1016/j.rser.2015.07.190.

Romieu, I., Gouveia, N., Cifuentes, L.A., de Leon, A.P., Junger, W., Vera, J., Strappa, V., Hurtado-Díaz, M., Miranda-Soberanis, V., Rojas-Bracho, L., Carbajal-Arroyo, L., Tzintzun-Cervantes, G. and HEI Health Review Committee. (2012). *Multicity study of air pollution and mortality in Latin America (the ESCALA study)*. Boston: Health Effects Institute. Available: http://pubs.healtheffects.org/getfile.php?u=874

Saremi, M., Rohmer, O., Burgmeier, A., Bonnefond, A., Muzet, A., & Tassi, P. (2008). Combined effects of noise and shift work on fatigue as a function of age. *International Journal of Occupational Safety and Ergonomics* : JOSE. 14(4): 387–394. DOI:10.1080/10803548.2008.11076779.

Schmit, C., & Lorant, V. (2009). Noise nuisance and health inequalities in Belgium: a population study. *Archives of Public Health*. 67(2): 52. DOI:10.1186/0778-7367-67-2-52.

Stansfeld, S., & Crombie, R. (2011). Cardiovascular effects of environmental noise: research in the United Kingdom. *Noise & Health*. 13(52): 229–233.

Stansfeld, S.A., & Matheson, M.P. (2003). Noise pollution: Non-auditory effects on health. *British Medical Bulletin*. 68: 243–257. DOI:10.1093/bmb/ldg033.

Syed, A., Hew, K., Kohli, A., Knowlton, G., & Nadeau, K (2013). Air Pollution and Epigenetics. *Journal of Environmental Protection*. 4: (114-122) DOI: 10.4236/jep.2013.48A1014

Su, J.G., Jerrett, M., de Nazelle, A. & Wolch, J. (2011) Does exposure to air pollution in urban parks have socioeconomic, racial or ethnic gradients? *Environmental Research*. 111(3): 319–328. DOI:10.1016/j.envres.2011.01.002.

Tenailleau, Q.M., Mauny, F., Joly, D., François, S. and Bernard, N. (2015). Air pollution in moderately polluted urban areas: How does the definition of "neighbourhood" impact exposure assessment? *Environmental Pollution*. 206 : 437-448. DOI:10.1016/j.envpol.2015.07.021.

Tobias, A., Recio, A., Diaz, J. and L.inares, C. (2014) Does traffic noise influence respiratory mortality? *European Respiratory Journal*. 44(3):797-799. DOI: 10.1183/09031936.00176213.

Tong, Z., Baldauf, R.W., Isakov, V., Deshmukh, P., Zhang, K.M. (2016). Roadside vegetation barrier designs to mitigate near-road air pollution impacts. *Science of the Total Environment*. 541: 920-927. DOI:10.1016/j.scitotenv.2015.09.067.

KH-BC-15-003-EN-N

Treasure, J. (n.d.) Sound Affects! Beaverton: Biamp Systems. United Nations, Department of Economic and Social Affairs, Population Division. (2014). *World Urbanization Prospects: The 2014 Revision*. Available: http://esa.un.org/unpd/wup/CD-ROM/Default.aspx [Accessed: 18th November 2015].

Van Kamp, I. and Davies, H. (2013). Noise and health in vulnerable groups: A review. *Noise & Health*. 15(64): 153-159.

Vienneau, D., Perez, L., Schindler, C., Probst-hensch, N., & Röösli, M. (2015). The relationship between traffic noise exposure and ischemic heart disease : a meta-analysis. *Environmental Research*. 138: 1–7. DOI:10.1016/j.envres.2015.02.023.

Whitehead, M. and Dahlgren, G. (2007). *Concepts and principles for tackling social inequities in health: Levelling up Part 1*. Copenhagen: WHO Regional Office for Europe. Available: http://www.euro.who.int/__data/assets/pdf_file/0010/74737/E89383.pdf

WHO. (2010). *Environment and health risks: a review of the influence and effects of social inequalities*. Copenhagen: WHO Regional Office for Europe. Available: http://www.euro.who.int/__data/assets/pdf_file/0003/78069/E93670.pdf

WHO. (2011). *Burden of disease from environmental noise*. Copenhagen: WHO Regional Office for Europe / JRC European Commission. Available: http://www.euro.who.int/__data/assets/pdf_file/0008/136466/e94888.pdf

WHO (2013a) *Health effects of particulate matter Policy implications for countries in eastern Europe, Caucasus and central Asia*. Copenhagen: WHO Regional Office for Europe. Available: http://www.euro.who.int/__data/assets/pdf_file/0006/189051/Health-effects-of-particulate-matter-final-Eng.pdf

WHO. (2013b). *Mental Health Action Plan 2013-2020*. Geneva: World Health Organization. Available: http://www.who.int/mental_health/action_plan_2013/en/

WHO Europe. (2011). *Burden of disease from environmental noise*. Geneva: World Health Organization Regional Office for Europe / JRC European Commission. Available: http://www.who.int/quantifying_ehimpacts/publications/e94888.pdf?ua=1

WHO Europe. (2015). *Development of WHO Environmental noise guidelines for the European Region*. Accessed: http://www.euro.who.int/en/health-topics/environment-and-health/noise/activities/development-of-who-environmental-noise-guidelines-for-the-european-region

WHO Europe, OECD (2015). *Economic cost of the health impact of air pollution in Europe: Clean air, health and wealth*. Copenhagen: WHO Regional Office for Europe. Available: http://www.euro.who.int/__data/assets/pdf_file/0004/276772/Economic-cost-health-impact-air-pollution-en.pdf

Yim, S.H.L., Lee, G.L., Lee, I.H., Allroggen, F., Ashok, A., Caiazzo, F., Eastham, S.D., Malina, R. & Barrett, S.R.H. (2015) Global, regional and local health impacts of civil aviation emissions. *Environmental Research Letters*. 10(3): 034001. DOI:10.1088/1748-9326/10/3/034001.

Zeka, A., Zanobetti, A. and Schwartz, J. (2005) Short term effects of particulate matter on cause specific mortality: effects of lags and modification by city characteristics. *Occupational Environmental Medicine* 62:718–725. DOI: 10.1136/oem.2004.017012

Publications Office