Unequal exposure and unequal impacts: social vulnerability to air pollution, noise and extreme temperatures in Europe

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Key messages

This report assesses inequalities in the exposure to and health impacts of selected environmental health hazards (air pollution, noise and extreme temperatures) on European society and discusses how these are addressed in policy and practice.

The uneven distribution of the impacts of air pollution, noise and extreme temperatures on the health of Europeans closely reflects the socio-demographic differences within our society.

- The elderly, children and those in poor health tend to be more adversely affected by such environmental health hazards than the general population (i.e. they are more vulnerable).

- Groups of lower socio-economic status (the unemployed, those on low incomes or with lower levels of education) also tend to be more negatively affected by environmental health hazards, as a result of their both greater exposure and higher vulnerability.

- In many European countries, the disproportionate exposure of lower socio-economic groups to air pollution, noise and high temperatures occurs in urban areas.

There are pronounced regional differences in social vulnerability and exposure to environmental health hazards across Europe.

- Regions with lower average socio-economic status and higher proportions of elderly people in southern and south-eastern Europe experience greater exposure to ground-level ozone and high air temperatures.

- Regions that are both relatively poorer and more polluted in terms of particulate matter (PM) are located mainly in eastern and south-eastern Europe. The link between socio-economic status and exposure to PM is also present at a finer-scale, local level.

- Wealthier sub-national regions tend to have higher average levels of nitrogen dioxide (NO_2), mostly because of the concentration of traffic and industrial activities in these locations. However, it is still the poorer communities that tend to be exposed to higher local levels of NO_2, as shown by studies at finer spatial scales.

Inequalities in exposure to environmental health hazards and their impacts on European society are only somewhat addressed by current policy and practice.

- International strategies and agreements (e.g. the United Nations' Sustainable Development Goals, the Paris Agreement or the World Health Organization's strategies) recognise the need for policy and action to focus on the protection of all, including the most vulnerable groups, against environmental health hazards.

- Within the EU, the links between social vulnerability and environmental health hazards are acknowledged in the Seventh Environment Action Programme, the air quality and noise directives and the EU strategy on adaptation to climate change. However, the EU policies do not explicitly require specific actions from the Member States to reduce inequalities in exposure and vulnerability.

- In relation to extreme temperatures, examples of practical responses aimed at reducing the impacts on vulnerable people include development of heatwave and cold wave action plans; improvements to housing and greening of neighbourhoods; and community-driven initiatives helping vulnerable people during extreme weather events.

- Fewer examples of actions aimed specifically at vulnerable groups have been identified in relation to air pollution and noise, as the mitigating measures usually target whole populations or specific locations, exceeding the limits or guideline concentration values.

- Road traffic management, promoting walking and cycling, nature-based solutions and good-quality housing are identified as effective responses to the combination of air pollution, noise and extreme temperatures that particularly benefit vulnerable groups.

The social inequalities in the impacts of and exposure to environmental health hazards are likely to continue in the future and thus require increased recognition in policy across governance levels.

- The projected climate change, air quality and noise trends combined with an ageing society and persisting socio-economic inequalities suggest that the geographical and societal differences in vulnerability and exposure are likely to continue in the future.

- Enhancing the coherence between EU policies on human health, climate change and the air pollution agenda in the EU policy framework may help to address the inequalities in environmental impacts. At a local level, multiple policy areas, from welfare policies to urban design, can help to reduce vulnerability as well as the population's exposure to environmental health hazards.

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Executive summary

Europe's environmental quality has been steadily improving over recent decades. Nonetheless, air pollution and noise continue to contribute to serious illnesses and premature deaths, especially in urban areas. In addition, recent years in Europe have been marked by extreme temperatures with severe implications for human health.

Exposure to air pollution, noise and extreme temperatures does not affect everyone in the same way. On the contrary, the uneven distribution of the impacts of air pollution, noise and extreme temperatures on the health of Europeans closely reflects the socio-demographic differences within our society. Personal characteristics, such as age or health, determine how sensitive people are to these environmental health hazards, i.e. how badly their health may be affected if they are exposed to them. In addition, people's ability to avoid, or cope with, these environmental health hazards is influenced by their socio-economic status (i.e. income, employment status or level of education). Older people, children, those experiencing material disadvantage and those in bad health are typically more vulnerable to air pollution, noise and extreme temperatures than the general population. They are also the ones who tend to have the least say in how and where they live, work or go to school, which, in turn, affects their exposure to these environmental health hazards. As a result, their health tends to suffer the most from the impacts of air pollution, noise and extreme temperatures (see Figure ES.1 on page 9).

The aim of this report is to assess inequalities in the exposure to and impacts of selected environmental health hazards (air pollution, noise, and extreme temperatures) on European society and to discuss how these are reflected in current policy and practice.

The assessment described in this report looks at the overlap between socio-demographic characteristics and the levels of exposure to environmental health hazards within sub-national regions. In many European countries, the disproportionate exposure of lower socio-economic groups to air pollution, noise and high temperatures occurs in urban areas, so the report also addresses cities.

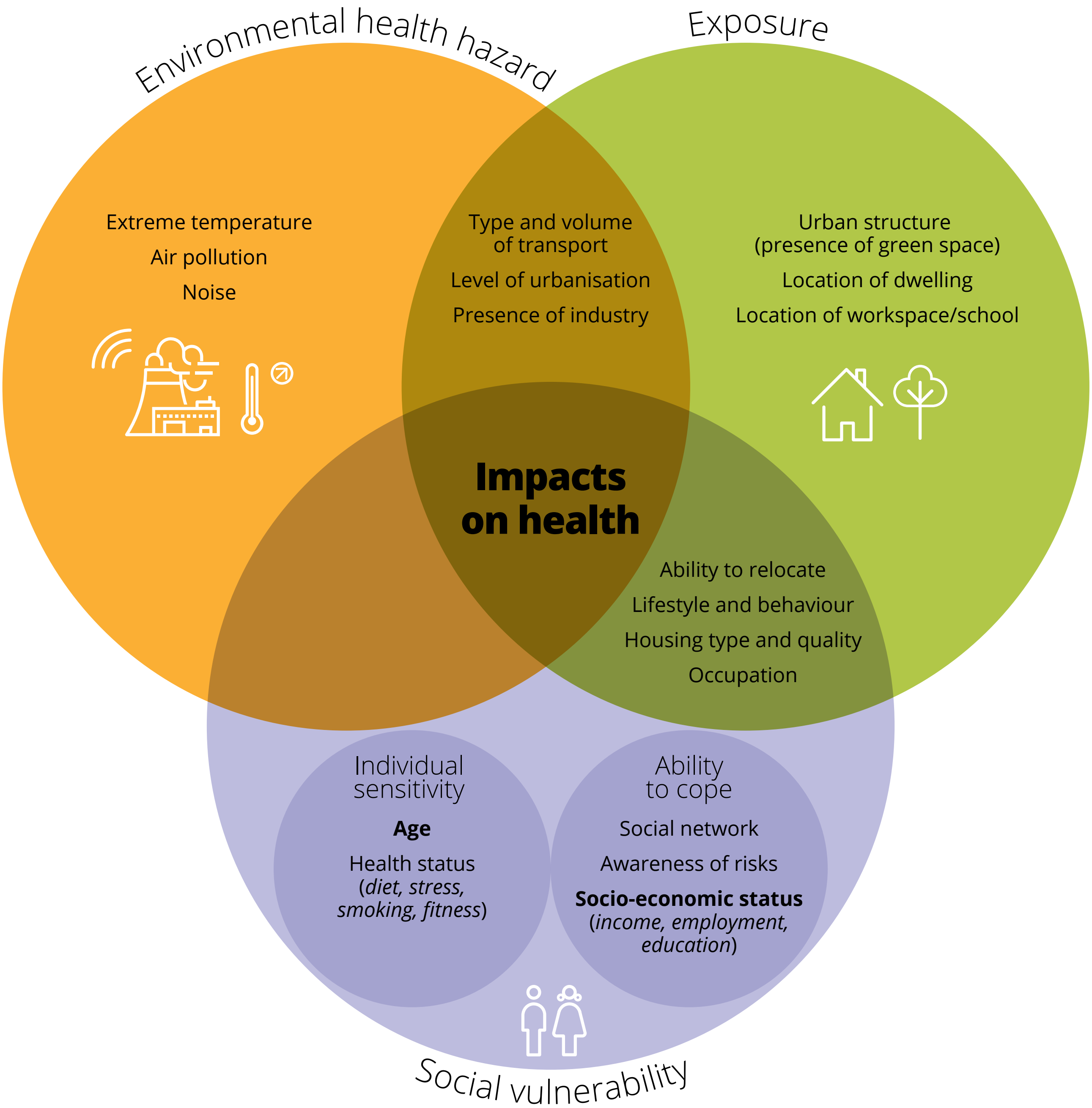
The assessment shows that across Europe there are pronounced large-scale regional differences in the levels of social vulnerability and exposure to environmental health hazards. For example, high temperatures and ozone pollution tend to affect the south of Europe to a greater extent than the north, while particulate matter pollution tends to be most concentrated in central and eastern Europe. Lower household incomes and higher unemployment are more prevalent in southern, central and eastern Europe, and both western and southern parts of Europe have a high proportion of the elderly in the population. Some regions with the lowest incomes and the highest unemployment rates are affected by extreme temperatures, which may affect the ability of the population to afford keeping homes adequately cool or warm. Consequently, in many regions, the population's high social vulnerability overlaps with high levels of environmental health hazards, resulting in negative health outcomes.

Within individual sub-national regions and cities, there are also stark inequalities in the impacts of environmental health hazards, which are linked to the varying vulnerability and exposure of different groups. In cities in particular, the neighbourhoods where residents' lives are shortened by air pollution and noise can be found next to areas of much better environmental quality, usually inhabited by more affluent communities.

The ongoing and projected changes in European society — for example, the rapid ageing in many western and southern countries or the continuing economical differences between the East and the West — mean that the inequalities in social vulnerability with regard to environmental health hazards are likely to persist or even increase. Furthermore, the changing climate has brought more extreme weather and climate events, which, especially when combined with persistent air pollution and noise, will continue to pose health risks. Consequently, the necessity of specific policies and actions aimed at protecting vulnerable groups from environmental health hazards should be explored further.

Currently, inequalities in the exposure to and impacts of environmental health hazards on European society are only somewhat addressed in policy and practice. The international strategies and agreements (e.g. the United Nations' Sustainable Development Goals, the Paris Agreement or the World Health Organization's strategies) tend to recognise the need for policy and action to focus on the protection of the most vulnerable groups against environmental health hazards. Also, key EU environmental policies, such as the Seventh Environment Action Programme, the air quality and noise directives and the EU strategy on adaptation to climate change, highlight the need to protect vulnerable groups from pollution and extreme temperatures. However, EU policies tend not to explicitly include actions targeting vulnerable groups.

Figure ES.1 Impacts on well-being of the combination of vulnerability and exposure to environmental health hazards



Sources: EEA, based on IPCC (2014b), WHO Europe (2010) and Aalbers et al. (2014). The report addresses the aspects of exposure and vulnerability to a varying extent.

This report also presents some examples of practical interventions targeting vulnerable groups. Road traffic management, promoting walking and cycling, nature-based solutions (e.g. tree planting) and good-quality housing are identified as effective responses to the combination of air pollution, noise and extreme temperatures that particularly benefit vulnerable groups. The impacts of extreme temperatures can be reduced by identifying the location of vulnerable individuals and areas, thus enabling a quick and targeted response; including specific groups in heat and cold action plans; and supporting bottom-up initiatives providing help to vulnerable people during extreme weather events. Fewer examples of actions targeting specifically vulnerable communities have been found in relation to air pollution and noise, as mitigating measures usually target entire populations or places exceeding the acceptable concentration values. The difficulties encountered when identifying examples of actions specifically aimed at vulnerable people emphasise the need for enhanced sharing of effective measures, especially at a local level.

Furthermore, a supportive policy framework is necessary to encourage actions targeting or considering the impacts of environmental health hazards on vulnerable groups. Enhancing coherence between policy areas is one of the ways to ensure more focus on vulnerable groups in the environmental context. In particular, increasing coherence between health, poverty, climate change and air pollution policies could bring measurable benefits to public health. At a local level, a multi-pronged approach in policy areas from welfare to urban design, that addresses locally specific hazards and vulnerabilities, can help to reduce inequalities in the health impacts of air pollution, noise and extreme temperatures.

1 Introduction

1.1 Rationale and aim

Safeguarding the European Union's (EU) citizens from environment-related pressures and risks to health is one of the main objectives of the EU's Seventh Environment Action Programme (7th EAP) (EC, 2013f). The European Commission (EC) recognises that a natural and living environment is a key aspect of quality of life (Eurostat, 2015a), due to the impact of the environment on human health. European citizens, scientists and policymakers are also increasingly interested in the influence of the environment on quality of life; four out of five Europeans see environmental issues as having a direct effect on their daily life and health (EC, 2017a).

The environmental quality across Europe has been steadily improving over recent decades. Nonetheless, environmental health hazards — both those that are strictly manmade, such as air pollution and noise, and the natural hazards exacerbated by human activity, such as extreme weather events — continue to affect European citizens. Air pollution and noise cause diseases and shorten lives. Heatwaves across Europe in recent years have resulted in thousands of fatalities, and cold spells bring on poor health and excess deaths (EEA, 2015; WHO Europe, 2012).

It is well recognised that the impacts of exposure to environmental health hazards differ among socio-demographic groups, defined according to age, employment status, and level of education or income. A plethora of studies indicates that the elderly, young children, those who are poorer and those already in bad health are affected the most by air pollution, noise or extreme temperatures (WHO Europe, 2012; Eurostat, 2015a). While Europe, compared with other world regions, has good provisions for healthcare and the social protection of the weakest members of society, the socio-economic inequalities persist; in fact, disparities in the levels of employment and gross domestic product (GDP) among and within the European countries have intensified after the onset of the global financial crisis in 2008 (OECD, 2017). While the wealth gaps have started to narrow again in recent years (EC, 2017c), stark differences in income and employment levels, educational attainment, GDP per head and health status are present not only between the member countries, but also among regions within each country, and even between neighbourhoods within cities. These differences translate into inequalities in health, with sizeable gaps existing within and between Member States of the EU (EC, 2013b). Furthermore, the population in parts of Europe is ageing rapidly, drawing attention to the increasing numbers of elderly people and their vulnerability to hazards such as heatwaves.

The 7th EAP highlights that European environmental policies need to focus particularly on areas where 'particularly sensitive or vulnerable groups of society ... are exposed to high levels of pollutants' (EC, 2013f, Annex, Article 45). Therefore, to facilitate development of such policies, it is important to understand where the presence of the most vulnerable groups overlap with high levels of pollution or extreme temperatures. While the differences between socio-demographic groups in terms of their exposure to environmental health hazards and subsequent impacts are addressed in the scientific literature investigated for individual cities, countries and regions, there is a paucity of up-to-date Europe-wide assessments that would help policymakers and citizens understand the character and scale of the socio-environmental inequalities in Europe (EC, 2016b).

This report has four main objectives:

- to assess the links between socio-demographic inequalities and exposure to selected environmental health hazards at various spatial scales in Europe;
- to draw attention to the differentiated impacts of selected environmental health hazards among different socio-demographic groups;
- to discuss how the unequal exposure of various socio-demographic groups and the unequal impacts of environmental health hazards on these groups are reflected in current policy and practice;
- to highlight the knowledge gaps.

By putting emphasis on the unequal distribution of environmental health hazards among socio-demographic groups, this report is building on the priorities in the European Environment Agency's (EEA) work programme, where human health is firmly in focus. It also provides an input into the forthcoming 2019 EEA report on the environment and health.

1.2 Scope

The report is based on the premise that in order to design potential policy interventions that would reduce inequalities in relation to environmental health hazards in Europe, the following areas need to be understood (Figure 1.1):

- the varying exposure (see Box 1.1 for definitions) of populations with different socio-demographic characteristics to selected environmental health hazards (air pollution, noise and extreme temperatures), i.e. the spatial overlap of these hazards and social vulnerability;
- the varying impacts of air pollution, noise and extreme temperatures on the health of different socio-demographic groups, i.e. to what extent their health is affected when they come into contact with the hazard;
- the current approaches to the protection of vulnerable groups from air pollution, noise and extreme temperatures — including international and European policy, as well as examples of actions at a national and sub-national level — addressing unequal exposure to and the unequal impacts of environmental health hazards on vulnerable groups.

The report investigates the above points by combining different sources and types of knowledge (summarised in Figure 1.1):

- a review of recent literature ([1]) about the associations between aspects of social vulnerability and environmental health hazards in various locations across Europe;
- a quantitative pan-European assessment of the spatial overlap of the socio-demographic characteristics of the population and the level of air and noise pollution (ETC/ACM, 2018a) or extreme temperatures. This assessment is exploratory and because of the scale of the analysis, it focuses on identifying patterns in exposure of different groups (rather than offering detailed insights), without implying any causality between social characteristics and environmental health hazards, or vice versa.
- a policy review, identifying how international and European policies tackle social vulnerability to environmental health hazards;
- examples and case studies from the European Environment Information and Observation Network (Eionet) countries and EEA resources, showing policy and practice responses targeted at vulnerable groups in relation to air or noise pollution, or climate-related impacts.

The report focuses on a limited number of environmental health hazards, namely air pollution, noise and extreme temperatures. The choice of the hazards included in the report was driven by both their significant impacts on human health and the availability of data at pan-European level. Other issues, such as chemicals and access to green space were not included. The upcoming 2019 EEA report on the environment and health will expand on these areas.

The report considers selected factors driving social vulnerability to environmental health hazards, namely socio-economic status, which is estimated by the average household income, unemployment and levels of educational attainment, and age (proportion of elderly people and young children among the population). In the reviewed body of evidence, socio-economic status and age are the most commonly addressed factors in relation to the impacts of and exposure to environmental health hazards. While the report does not present the full picture of social vulnerability to environmental health hazards across Europe, the strong links between socio-economic status, age and health help to create an understanding of the range of impacts of environmental health hazards on different groups.

([1]) A systematic keyword search of scientific literature databases was carried out; however, it was limited to the English language and important studies in other languages could have been missed. Furthermore, no literature has been found for some of the member countries of the European Environment Agency. There is also a varying level of evidence available for different environmental health hazards and vulnerable groups. See Barnes et al. (2018) for details on the review pertaining to air quality and noise pollution. The same approach was followed to carry out the review on extreme temperatures.

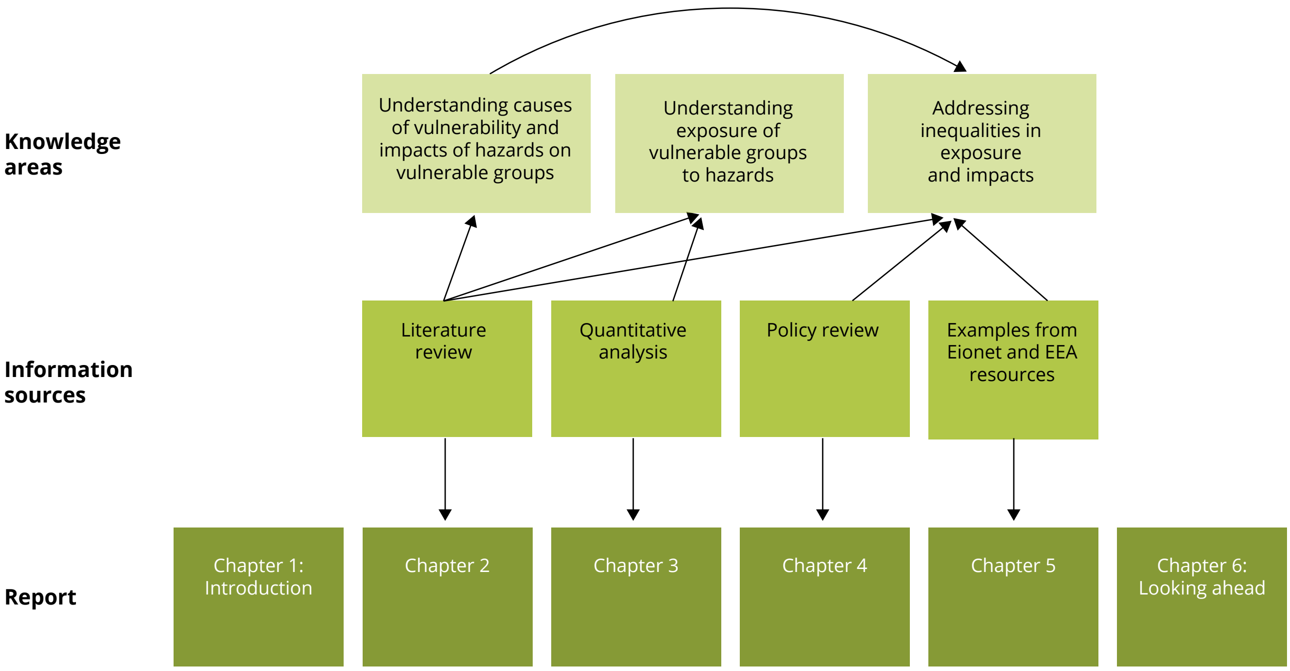
Box 1.1 Terms used in this report

After the constitution of the World Health Organization (WHO, 1946), health is understood as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.

The terms relating to a population's contact with and susceptibility to environmental health hazards, as well as the impacts they experience, are based on the terminology used by the EEA ([2]) and the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC, 2014a). The definitions have been adjusted to the scope of this report:

- **Environmental health hazard** is the occurrence of a natural or human-induced physical event or a physical impact that may cause loss of life, injury or other health effects. In the context of this report, environmental health hazards are air pollution, noise and extreme temperatures.
- **Social vulnerability** is the propensity or predisposition of people (individuals or a population of a given area) to be negatively affected by external stressors, including environmental health hazards. It could be seen as the combination of **sensitivity** (or susceptibility to harm) and **lack of capacity to avoid, cope with or adapt** to environmental health hazards. Sensitivity is largely driven by age and health, while the ability to cope is linked to socio-economic status, social support available or awareness of risks.
- **Exposure** is the presence of people in places and settings that could be adversely affected by hazards.
- **Impacts** are the effects on human health due to the interaction of environmental health hazards and the vulnerability of an exposed population or community.

Figure 1.1 Sources of information and structure of the report



([2]) https://www.eea.europa.eu/help/glossary (accessed 26 November 2018).

1.3 Structure of the report

Chapter 2 begins by explaining how social vulnerability combined with exposure to air pollution, noise and extreme temperatures results in negative health outcomes. It then provides an overview of evidence regarding the impacts of environmental health hazards on the general population and selected vulnerable groups, and the exposure of vulnerable groups in Europe to environmental health hazards.

Chapter 3 presents an exploratory assessment of the associations between social vulnerability and environmental health hazards for the whole of Europe. It looks at air pollution, noise and extreme temperatures in turn, closing with a brief insight into the European population's exposure to multiple hazards.

Chapter 4 describes the response to unequal exposure and the unequal impacts of air pollution, noise and extreme temperatures in international and European policy.

Chapter 5 provides some examples of actions addressing the unequal impacts of environmental health hazards on vulnerable groups.

Chapter 6 outlines some of the future projections shaping social vulnerability and environmental health hazards in Europe. It also discusses opportunities for further consideration of social vulnerability in policy at different spatial scales and highlights knowledge gaps.

This report is underpinned by additional publications, providing supplementary information:

- Analysis of air pollution and noise and social deprivation, which reports the detailed methodology and the results of statistical analyses on the associations between social vulnerability, and air and noise pollution across Europe (ETC/ACM, 2018a).
- Social vulnerability to climate change in European cities — state of play in policy and practice, which discusses the notion of social vulnerability to climate change, reviews the guidance available to local authorities for considering social issues in adaptation and presents case studies of adaptive actions focusing on social impacts of the changing climate (ETC/CCA, 2018).
- Qualitative assessment of links between exposure to noise and air pollution and socioeconomic status, summarising the evidence review on links between exposure to noise and air pollution, and socio-demographic characteristics (Barnes et al., 2018).

2 Environmental health hazards and social vulnerability: evidence review of exposure and impacts across Europe

Key messages

- Air pollution and high temperatures have particularly negative effects on the elderly, children and those with pre-existing health problems. The homeless, and those living in inadequate housing or unable to afford heating, are the most affected by the cold.
- People of lower socio-economic status tend to live, work and go to school in places with worse air quality and higher levels of noise. In many cities, poorer communities are exposed to higher temperatures as a result of the urban heat island effect.
- The disproportionate exposure of lower socio-economic groups to air pollution and road noise is largely driven by land use planning and the housing market. Housing quality affects exposure to extreme temperatures among the vulnerable groups.

2.1 Impacts on health: a combination of hazards, exposure and vulnerability

The quality of the local environment influences people's health by determining their level of exposure to environmental health hazards. The impacts that such hazards subsequently have on health depend on an individual's tolerance of hazard levels and their ability to recover from the impacts and to adapt to future circumstances to avoid such hazards. Consequently, the health effects associated with air pollution, noise and extreme temperatures result from a combination of environmental conditions, exposure to them and individual susceptibility to harm (Figure 2.1).

Social vulnerability refers to the inability of particular social groups to withstand the adverse impacts of environmental health hazards, because of particular characteristics of those groups (see also Box 1.1 for an explanation of terms). Children, the elderly, those in poor health or with unhealthy behaviours such as smoking, may demonstrate increased sensitivity to environmental stressors and therefore experience more acute impacts than a healthy adult subject to the same level of exposure. Socially vulnerable groups may also suffer limitations in their ability to access and use health services to seek treatment for health outcomes associated with exposure to environmental health hazards (WHO Europe, 2012).

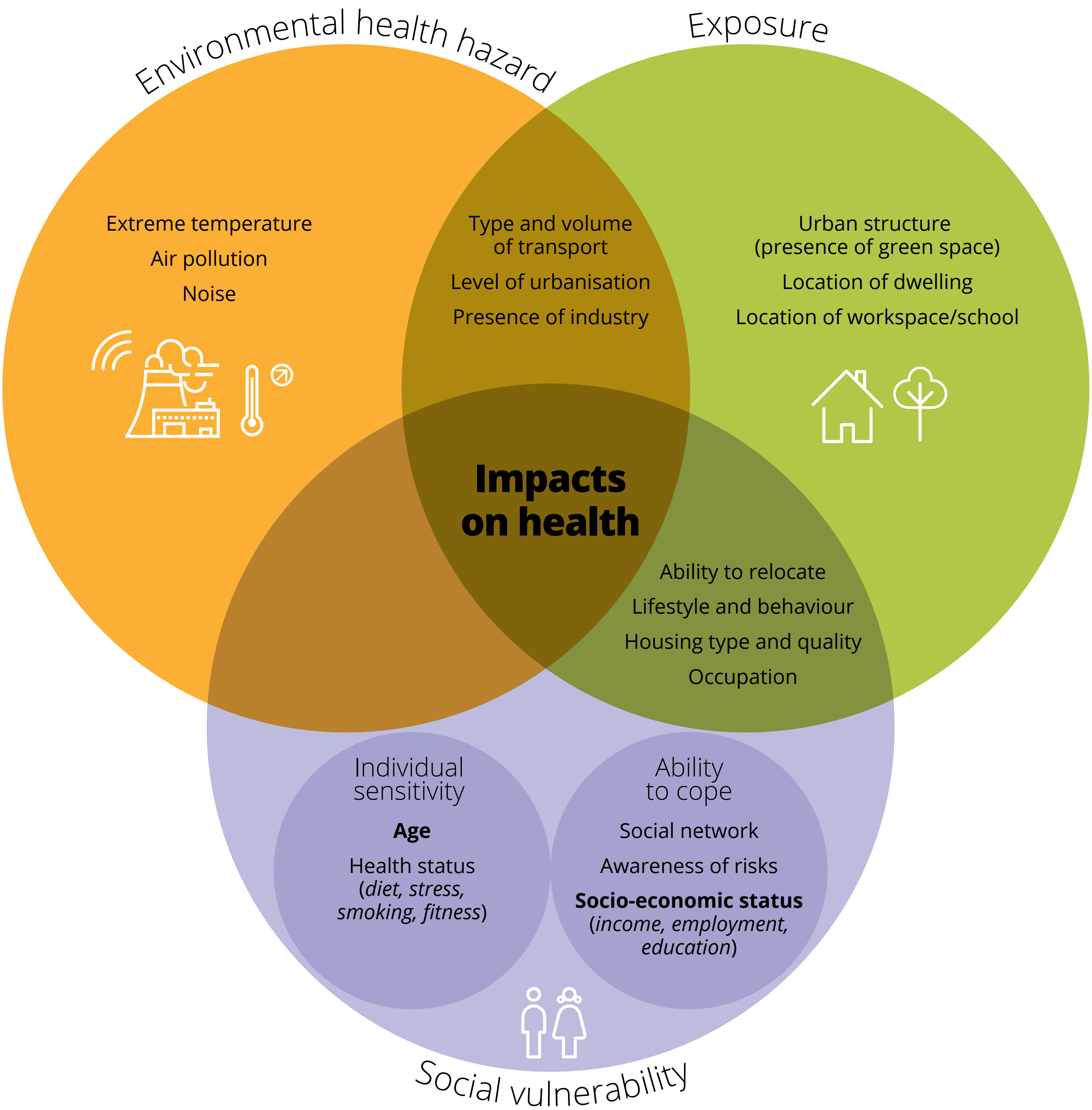
The combination of higher exposure to environmental health hazards in low socio-economic groups and their increased susceptibility to the effects of exposure (primarily as a result of stress, fewer opportunities to choose health-promoting behaviours and poorer health status) results in health disparities driven by environmental factors. This has been described as the 'triple jeopardy' effect (Jerrett et al., 2001); for some individuals in low socio-economic status groups (e.g. children or the elderly), their biological sensitivity adds another dimension to their vulnerability, resulting in a 'quadruple jeopardy'. This report considers two principle causes of social vulnerability to environmental health hazards: age and socio-economic status.

2.1.1 Why might certain groups be more vulnerable?

The reasons why certain individuals in society may be more vulnerable to the impacts of environmental risks are complex and relate to the specific circumstances of the individual, such as their age, their pre-existing health condition and their particular behaviours.

The elderly are more sensitive to heat because of the prevalence of health conditions they are subject to, such as dementia and chronic diseases. Conditions that affect an elderly individual's ability to keep cool include Parkinson's disease and Alzheimer's, as well as the use

Figure 2.1 Impacts on well-being of the combination of vulnerability and exposure to environmental health hazards



Sources: EEA, based on IPCC (2014b), WHO Europe (2010) and Aalbers et al. (2014). The report addresses the aspects of exposure and vulnerability to a varying extent.

of certain medications that may cause dehydration. Age can also reduce the ability to cope with high temperatures, since older people are more likely to live alone and are less physically able to care for themselves (Koppe et al., 2004; Semenza et al., 1999). The elderly are more sensitive to air pollution, as a result of frailty, reduced lung function and co-existing chronic lung, heart or circulatory conditions, which may worsen following the individual's exposure to environmental pollutants (Simoni et al., 2015).

At the other end of the demographic scale, infants and young children are more prone to heat-related illnesses because of their less developed thermoregulation and limited ability to influence their surroundings (Padilla et al., 2016; Kovats et al., 2004; Xu et al., 2012). Children have higher respiratory rates than adults and, consequently, higher exposure to air pollutants. Infants and young children may inhale higher levels of pollutants than adults as a result of mouth breathing. Furthermore, children's immune systems and developing organs are not mature and are therefore more affected by both air pollution and noise than adults (Kim and American Academy of Pediatrics Committee on Environmental Health, 2004; van Kamp and Davies, 2013). Children may also have less developed coping strategies when faced with environmental noise (Clark and Paunovic, 2018).

Socio-economic status is an important determinant of health. The most deprived people in society often have poor diets and rely on sub-optimal access to quality healthcare, in addition to suffering from stress; all of these can add up and make individuals more sensitive to environmental health hazards (Khreis et al., 2017). In almost every country in Europe, chronic health problems are more prevalent among those on the lowest incomes, compared with people on the highest incomes. People with lower levels of educational attainment, lower incomes or manual jobs tend to die younger and suffer more often from serious health issues (Eurostat, 2018a). For example, in the United Kingdom in 2008, the number of deaths from cardiovascular disease in the poorest 20 % of the population was 50 % higher than in the richest 20 % (Paavola, 2017). The health of people of lower socio-economic status exposed to noise and air pollution tends to be more affected when compared with those of higher socio-economic status. This is a result of long-term health conditions, poor housing, inadequate diets and suffering from stress (EC, 2016b; Kim et al., 2018; Cournane et al., 2017b; Holgate, 2017).

2.1.2 Why might vulnerable groups face increased exposure?

A large body of evidence suggests that people of lower socio-economic status tend to live in worse environmental conditions with respect to noise and air pollution, although national and regional differences are also observed. A complex mix of social, economic, political, psychological and environmental factors influence how environmental risks are distributed across society (Kruize et al., 2007). Evidence suggests that the most important drivers are land use, urbanisation, and the housing and job markets. To some extent, the under-participation of vulnerable groups in local decision-making processes regarding land use planning leads to an increased presence of polluting installations or, in urban settings, a lack of green spaces offering respite from heat in the vicinity of their housing. Older people, children and low-income groups may also participate to a lesser extent in decision-making processes.

Land use and urbanisation

The characteristics of the place where people live — in particular the density of built-up areas and concentrations of traffic and industry — are the main factors explaining the general higher exposure of lower socio-economic groups to air pollution, noise and higher temperatures compared to rural areas. In many European countries, in particular in western Europe ([3]), deprivation is concentrated in urban areas; in 2014, there were 34 million people living in EU cities who were at risk of poverty or social exclusion (Eurostat, 2018c). People of lower socio-economic status tend to live in areas that have more traffic leading to higher levels of air pollution and noise. This has been found, for example, in the United Kingdom (for nitrogen dioxide (NO_2) concentrations) (Barnes and Chatterton, 2017; Paavola, 2017), in Germany (Flacke et al., 2016; Franck et al., 2014) and in France (Padilla et al., 2016).

The intensity of traffic in urban areas means that air quality is typically significantly worse in densely built-up cities than in less populated rural areas. For example, poor air quality was more likely in highly populated areas than in less densely populated areas in Wallonia, Belgium (Lejeune et al., 2016). However, the picture is not straightforward. Both air and noise pollution follow a linear pattern along major roads and motorways in the urban fringe, consequently

([3]) The references to western, central and eastern, northern and southern Europe in this report follow the classification used by EuroVoc. See https://publications.europa.eu/en/web/eu-vocabularies (accessed 22 October 2018).

affecting wealthier communities that tend to live there as well. Some wealthy zones of European cities, such as central London, are also exposed to high levels of NO_2 pollution because of the high volume of traffic (Shrestha et al., 2016; Saunders et al., 2017). So while socio-economic deprivation overlaps with air pollution and noise in European cities, there are notable exceptions.

The urban heat island (UHI) phenomenon, whereby cities are significantly warmer than nearby rural areas because of the high absorption and retention of heat by artificial surfaces (see also Section 2.4.3), is closely linked to the density and extent of the built environment. There is a substantial increase in mortality as a result of heat stress in dense urban areas. For example, heat-related mortality in cities in the West Midlands (United Kingdom) during the 2003 heatwave was twice as high as that in surrounding rural areas (Heaviside et al., 2016a). Similarly, a link was found between the number of deaths caused by high temperatures during the 1990 and 2006 heatwaves and the proportion of land covered by impervious surfaces in the German Federal State of Brandenburg (Gabriel and Endlicher, 2011). Green space in urban areas provides a cooling function, mitigating the UHI effect; vegetation can also buffer noise and improve air quality in urban residential areas (WHO Europe, 2016a). However, green spaces are not always equitably distributed across cities (Poelman, 2018; ten Brink et al., 2016). For example, research in Germany found that more deprived neighbourhoods had less green space and suggested that this might amplify health inequalities in the urban environment (Schüle et al., 2017). In the city of Kalisz, Poland, over two thirds of children and people over 65 years old live in the city centre or in surrounding housing estates, which are characterised by a low proportion of green space (Cichocki et al., 2016).

Influence of the housing market on location of dwellings

The spatial distribution of groups of different socio-economic status in urban areas, where differences tend to be the starkest, is largely driven by the housing market and housing policies (Aalbers et al., 2014). For example, the availability of older, cheaper housing and small flats in apartment buildings explains the presence of lower income groups in the central areas of many European cities. Poorer people have less choice in where they live and end up residing in less attractive neighbourhoods. Furthermore, low-income groups tend to live in city centres or industrial areas because of better access to work (Davoudi and Brooks, 2012; Glaeser et al., 2008).

A poor-quality environment can lower local house prices, making properties more affordable and therefore attractive to people with lower incomes (Aalbers et al., 2014). There is evidence that house values are reduced in noisy areas (EEA, 2014a; Le Boennec and Salladarré, 2017). Conversely, apartments located in quiet districts of Paris are worth, on average, 1.5 % more than apartments in noisy districts (Bureau and Glachant, 2010). In Oslo and Drammen, Norway, people on higher incomes live close to the city centres, yet they tend to live in more expensive, quiet neighbourhoods because they are more capable of 'paying themselves out of the noise' (Fyhri and Klæboe, 2006). Aircraft noise may negatively affect house prices to an even greater extent than road traffic noise (Kopsch, 2016; Trojanek et al., 2017) and in Switzerland, railway noise led to a greater reduction in house prices than road noise (BAFU, 2018). However, house prices are context dependent and the noise level does not always constitute a significant variable (Cavailhès, 2005).

In the European context, no clear associations have been found between air pollution levels and house prices, presumably as the effects of air pollution are less readily apparent than noise, even at levels that may be damaging for health.

Housing conditions

The physical state of dwellings, including thermal isolation, heating and cooling systems, and insulation from noise affect exposure to environmental stressors inside the home. Poor housing conditions and buildings lacking in natural or artificial shading can lead to increased thermal stress in areas affected by high temperatures (Liu et al., 2017). Substandard dwellings, inhabited by poorer communities, were found to be more prone to overheating in London, United Kingdom (Wolf and McGregor, 2013; Liu et al., 2017), and the Greek cities of Thessaloniki (Yiannakou and Salata, 2017) and Athens (Keramitsoglou et al., 2013).

Similarly, low-income households have been found to be affected by the cold during winter because of the poor quality of the buildings combined with sparse use of heating (Santamouris et al., 2014); housing standards, in particular thermal efficiency, have been found to influence the excess winter mortality in southern and western European countries characterised by high poverty and inequality levels (Healy, 2003). Vasconcelos et al. (2013) established that a high percentage of inpatients with myocardial infarctions in Portugal lived in dwellings with little or no heating.

Heat rises and is easily transferred through thin ceilings, meaning that people residing on the top floor of apartment buildings are more prone to overheating and experience higher rates of heat-related morbidity and mortality than those on lower floors (Koppe et al., 2004). The relationship between the top floor of a dwelling and heat stress was found, for example, in Nuremberg, Germany (Seebaß, 2017) as well as in Paris, where just over half the victims of the 2003 heatwave lived on the top two floors in traditional Parisian 'service rooms', often occupied by the elderly (Poumadère et al., 2005). Deprived populations also experience worse effects from noise due to poorer housing (EC, 2016b). Ensuring the affordability of appropriately insulated and ventilated housing in quiet locations with good air quality is, therefore, key to reducing the exposure of vulnerable groups to environmental health hazards.

Occupational exposure

People of lower socio-economic status are more likely to work outdoors or in places affected by air pollution or extreme temperatures. People working close to roads with high air pollution (e.g. traffic police) or with noisy equipment (e.g. park workers operating grass mowers) have been found to have increased blood pressure due to the levels of exposure (Tomei et al., 2017). Those working outdoors in big cities have been found to have worse hearing than those working indoors (Caciari et al., 2013). Health risks during heat extremes are greater for people who carry out physical work outdoors or in a hot environment (e.g. manual labourers) (Hanna et al., 2010; Lucas et al., 2014). In contrast, higher income groups tend to work indoors, which reduces their exposure (Hajat et al., 2015).

2.2 Air pollution: impacts and exposure

2.2.1 Impacts on health

Air pollution is the single largest environmental health risk in Europe. It increases the incidence of a wide range of diseases, mainly respiratory and cardiovascular diseases. The International Agency for Research on Cancer (IARC) has classified air pollution in general, as well as particulate matter (PM) ([4]) as a separate component of air pollution mixtures, as carcinogenic (IARC, 2013). There is also emerging evidence that exposure to air pollution is associated with new-onset type 2 diabetes in adults and it may be linked to obesity, systemic inflammation, Alzheimer's disease and dementia (RCP, 2016; WHO Europe, 2016b).

Consequently, the burden of disease (see Box 2.1) resulting from air pollution is substantial. The most common reasons for premature deaths attributable to air pollution are heart disease and stroke, which are responsible for 80 % of premature death cases, followed by lung diseases and lung cancer (WHO, 2014). Among air pollutants, fine PM is the most deadly; the EEA estimates that in 2015 about 391 000 premature deaths in the 28 EU Member States (EU-28) were attributed to $PM_{2.5}$ ([5]) concentrations (422 000 premature deaths across 41 European countries) (EEA, 2018a).

When considering the YLL (see Box 2.1) per 100 000 inhabitants, the largest impacts of $PM_{2.5}$ are observed in central and eastern European countries, where the highest concentrations are also detected (i.e., in order of relative impacts, Kosovo under United Nations Security Council Resolution 1244/99, Bulgaria, Serbia, the former Yugoslav Republic of Macedonia, Hungary, Poland and Romania). The lowest relative impacts are found in countries located in the northern and north-western edges of Europe: Iceland, Norway, Ireland, Sweden and Finland. For NO_2, the highest rates of YLL per 100 000 inhabitants are found in Italy, Greece, Spain, France and Germany, with the lowest rates in the north of Europe. For ozone (O_3), Kosovo, Montenegro, Hungary, Serbia, Greece and Croatia have the highest rates of YLL per 100 000 inhabitants (Map 2.1) (EEA, 2018a).

2.2.2 Impacts on vulnerable groups

A considerable body of evidence suggests that the health of people of lower socio-economic status tends to be more affected by air pollution than the health of the general population. The sensitivity of the former can be increased by their overall worse health, as a result of other factors, including diets, lifestyle, inadequate healthcare or stress (Khreis et al., 2017). For example, in Wales, all-cause and respiratory disease mortality rates were highest in the most deprived areas, as air pollution strengthened the effect of deprivation on health (Brunt et al., 2017). In

([4]) Particulate matter is a collective name for fine solid or liquid particles added to the atmosphere by processes on the Earth's surface. Particulate matter includes dust, smoke, soot, pollen and soil particles (https://www.eea.europa.eu/help/glossary; accessed 26 November 2018).

([5]) Particulate matter with an average aerodynamic diameter of up to 2.5 µm (https://www.eea.europa.eu/help/glossary; accessed 26 November 2018).

Box 2.1 Measuring the impacts of environmental health hazards on the population

The impacts of air pollution, noise and extreme temperatures on human health at the population level can be measured or estimated in different ways. In relation to extreme temperatures, the impacts on population are mainly observed during extreme weather events or during a relatively short period afterwards. These impacts are usually measured by mortality and morbidity. **Morbidity** refers to the state of being diseased or unhealthy. The morbidity rate can be measured, for example, by the percentage of people in a given population admitted to hospitals during a certain period. The **mortality** rate (death rate) is the number of deaths in a population within a given period. The extra morbidity and mortality associated with extreme weather events are frequently measured by comparing a period in a given year with corresponding periods in reference years.

Prolonged exposure to lower than optimal temperatures also results in considerable health impacts and is measured as **excess winter deaths**, which is the ratio between average daily deaths between December and March versus other months. This measure is commonly used to assess health burdens associated with winter weather, although it is not without criticism, as it is affected by the number of deaths in the summer months (Hajat and Gasparrini, 2016).

In the case of exposure to air pollution or noise, one of the commonly used impact measures is the number of **premature deaths**, i.e. deaths that occur before a person reaches an expected age. This expected age is typically the average life expectancy for a country and gender. Premature deaths are considered to be preventable if their cause can be eliminated.

The burden of disease is a measure of the gap between the current health status and an ideal situation in which everyone lives into old age free from disease and disability. The disease burden tends to be expressed in **disability-adjusted life years (DALYs)**, where one DALY is one lost year of 'healthy' life, on account of a disease, injury or risk factor. The burden of disease is the sum of these DALYs across the population. Therefore, DALYs standardise health effects by expressing in one number the number of people affected and the duration and severity of the health effects.

Years of life lost (YLL) are defined as the years of potential life lost owing to premature death, on account of a disease, injury or risk factor. It is an estimate of the average number of years that a person would have lived if he or she had not died prematurely. YLL takes into account the age at which deaths occur and is greater for deaths at a younger age and lower for deaths at an older age. It provides, therefore, more nuanced information than the number of premature deaths alone. DALYs are the sum of the years of life lost (YLL) due to premature mortality within a population and the years lost due to disability (YLD) for people living with a health condition or its consequences.

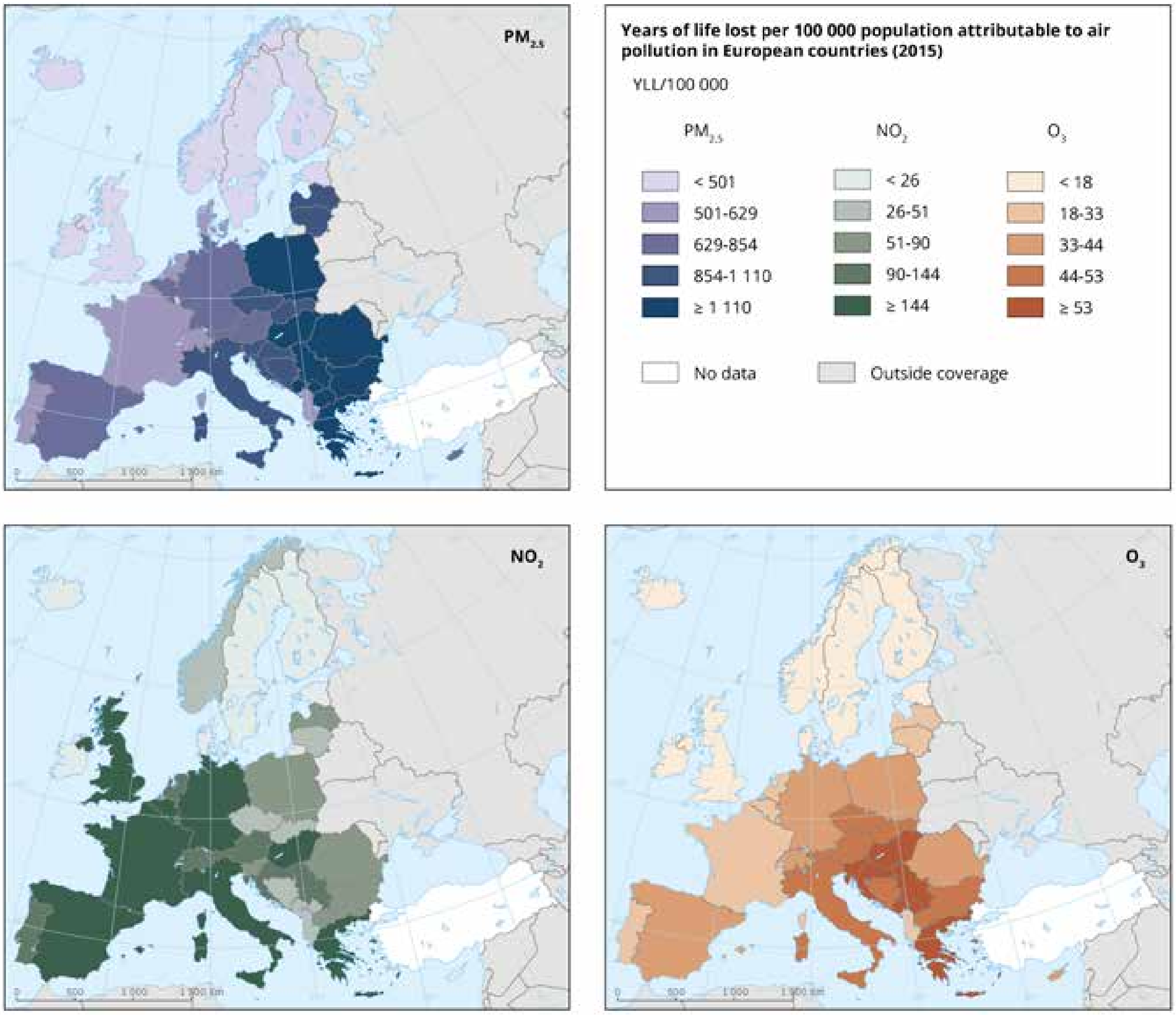
Sources: López et al., 2006; WHO (n.d.)

Dublin, Ireland, analysis of air pollution and hospital admissions for cardiovascular and respiratory diseases identified higher mortality risk among those from lower socio-economic groups (Cournane et al., 2017a). In Rome, Italy people of lower socio-economic status, who generally live on the outskirts of the city, were more likely to die from diseases associated with the effects of PM_{10} (such as heart failure and chronic obstructive pulmonary disease) than the wealthier residents in the more polluted city centre, due to their greater susceptibility associated with existing diseases and lifestyle factors (Forastiere et al., 2007). However, other studies suggest less straightforward links — for example, the influence of deprivation and NO_2 exposure on infant and neonatal mortality in France varied depending on the area and time period considered (Padilla et al., 2016).

Air pollution affects children's health (WHO, 2005; WHO Europe, 2013d). The occurrence of bronchitis, pneumonia and sinusitis in pre-school children in deprived areas of Saxony-Anhalt, Germany, was associated with the location of kindergartens in relation to car traffic; the further the kindergarten was from a busy road, the lower the likelihood that children would contract one of these diseases (Gottschalk, C., et al., 2011). In addition, air pollution has a negative effect on children's neural development and cognitive capacities, which, in turn, can affect their performance both at school and later in life, leading to lower productivity and quality of life (UNICEF, 2017). A study of children in Barcelona, Spain, found that even short periods of exposure to higher concentrations of air pollution were associated with adverse impacts on cognitive development (Alvarez-Pedrerol et al., 2017). In a longitudinal study of Swedish children and adolescents, levels of neighbourhood air pollution were associated with medications dispensed for certain psychiatric disorders (Oudin et al., 2016).

Older people's physical and mental health tends to suffer more from exposure to air pollution than the health of the general population. In London, air pollution levels were associated with the number of

Map 2.1 Years of life lost per 100 000 inhabitants attributable to air pollution in European countries (2015)



Note: The classification of values in map legends is quantiles (five equal-sized classes).

Source: Based on EEA (2018a).

older people admitted to hospitals for cardiovascular and respiratory diseases (Halonen et al., 2016). Similarly, in Dublin, a higher 30-day mortality in elderly hospital patients was linked to higher nitrogen oxide (NO_x) pollution on their admission day (Cournane et al., 2017b). Longer term exposure to air pollution is associated with increased levels of anxiety and stress among older people (Oudin et al., 2016). The cumulative effects of various air pollutants on the elderly are also evident: long-term NO_2 exposure is likely to exacerbate the short-term effects of exposure to PM (Faustini et al., 2016).

Those with pre-existing health problems also tend to be especially affected by air pollution. Heart attack survivors in Greater London were more likely to be re-admitted to hospitals and suffer from higher mortality rates if they had been exposed to long-term air pollution (Tonne et al., 2016). In Dublin, patients with disabling disease were at a higher risk of mortality if they were admitted on days with high air pollution (Cournane et al., 2017b). However, in another study, pre-existing risk factors for stroke (including pre-existing health conditions) did not increase susceptibility to the adverse effects of air pollution on stroke risk (Maheswaran et al., 2016).

Consequently, people of lower socio-economic status, the very old, the very young and those with pre-existing health problems are more likely to suffer negative health outcomes as a result of air pollution. However, the conclusions drawn for these groups may not be true for all individuals in the group or for all locations in general, as individual lifestyle factors, hereditary issues and living and working environments affect vulnerability and exposure.

2.2.3 Exposure of vulnerable groups to air pollution

There is abundant evidence emerging from various European locations on the associations between socio-economic status and air pollution. For example, nearly half of the most deprived neighbourhoods in London are exposed to NO_2 values exceeding EU limits, compared with just 2 % of the least deprived neighbourhoods (Aether, 2017b). Similar observations on exposure to air pollution being higher for groups of lower socio-economic status were made in Dortmund, Germany, for PM_{10} and NO_2 (Shrestha et al., 2016), Ostrava, Czechia (Šlachtová et al., 2016), Wales (Brunt et al., 2017), Lille and Marseille, France (for NO_2) (Padilla et al., 2016), Grenoble and Lyon, France (Morelli et al., 2016), Wallonia, Belgium (Lejeune et al., 2016), Malta (WHO Europe, 2013b) and the Netherlands (Fecht et al., 2015).

However, the association between socio-economic status and air pollution levels is highly location and scale specific. For example, research carried out in Sweden found that in some cities socio-economic status and the levels of NO_2 in an area of residence are associated, but the associations vary considerably, even between cities in the same county (Stroh et al., 2005). In Bristol, England, and Rotterdam, the Netherlands, the most and least deprived neighbourhoods were both exposed to similar concentrations of PM_{10} and NO_2. This may be due to the desirability of city centre living among more affluent people (Fecht et al., 2015); in Rome, people of higher socio-economic status were exposed to higher levels of NO_x and PM_{10} because they lived in central city locations with high volumes of traffic (Forastiere et al., 2007).

In addition, the type of settlement that vulnerable groups live in is associated with exposure to air pollution. For example, Branis and Linhartova (2012) found that, in Czechia, communities with lower levels of education and higher unemployment tended to reside in smaller cities with higher concentration levels of combustion-related air pollutants (SO_2 and PM_{10}), whereas those on higher salaries and with higher educational attainments tended to live in larger cities and were exposed to higher levels of NO_2. In England, PM concentrations were found to be generally higher in areas of greater socio-economic deprivation; however, the pollution-deprivation relationships varied by urban-rural status (Milojevic et al., 2017). While some general conclusions can be drawn from local studies on the links between socio-economic status and air pollution exposure, they may not be equally applicable to all situations across Europe.

There is limited and mixed evidence in terms of the exposure of older people and children to air pollution compared with the general population's exposure. In the Spanish cities of Madrid and Barcelona, areas with higher numbers of children aged 0-4 were less exposed to NO_2 compared with the city as a whole, while elderly people were exposed to higher levels of NO_2, because of their over-representation in inner city neighbourhoods (Moreno-Jiménez et al., 2016). A study in London did not find substantial differences in exposure to air pollution between under-19s or over-65s and the general population (Aether, 2017b). Nonetheless, the exposure of children from groups of lower socio-economic status is particularly concerning on account of cumulative vulnerability factors potentially exacerbating the health impacts of air pollution. In London, over 85 % of the schools most affected by poor air quality had pupils who lived in areas more deprived than the London average (Aether, 2017a). In Malmö, Sweden, exposure of children aged 7-15 to NO_2 in their place of residence and at school regularly increased as the socio-economic status of a child's neighbourhood decreased (Chaix et al., 2006).

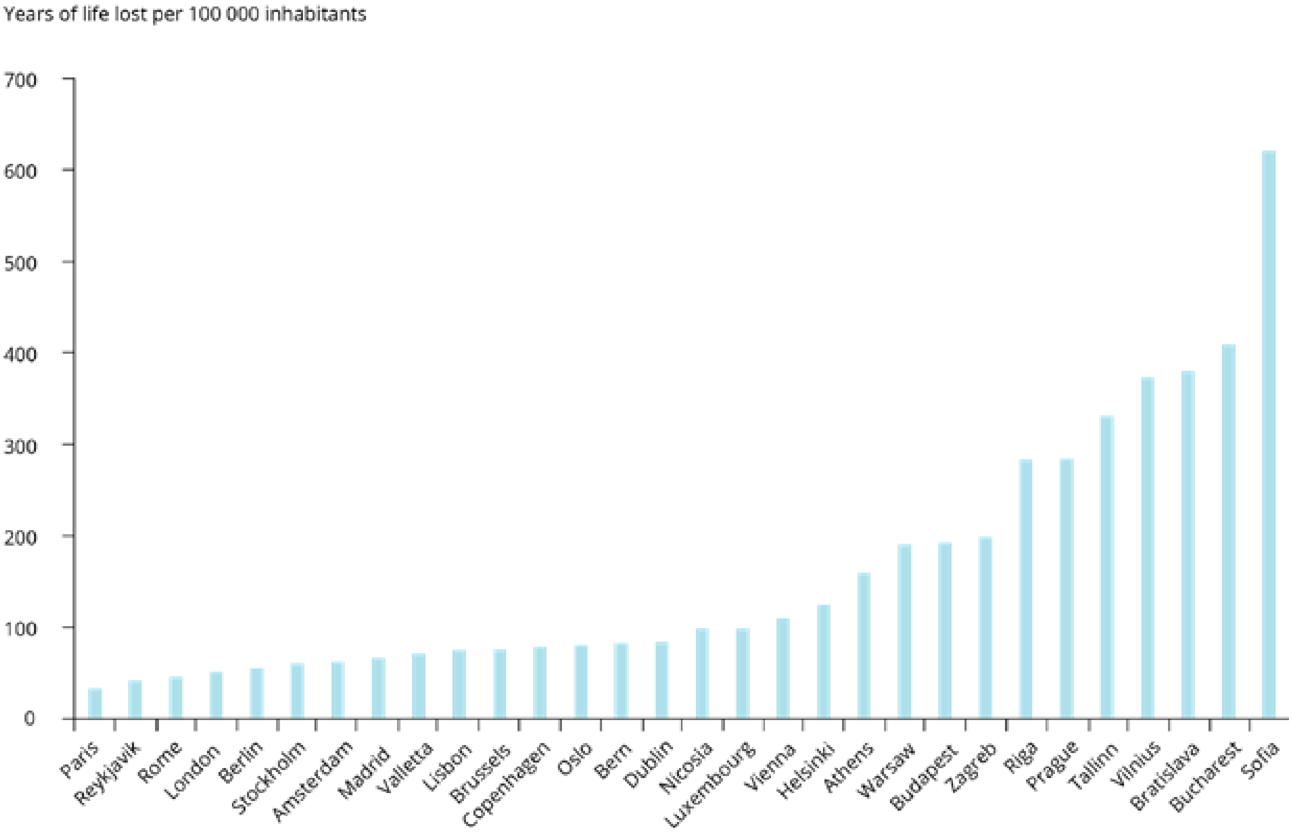
As can be seen from the evidence presented above and in Section 2.2.2, socio-economic status tends to be linked to exposure and vulnerability, while age factors, although they affect vulnerability, are not so strongly linked to exposure in the place of residence.

2.3 Noise: impacts and exposure

2.3.1 Impacts of noise on health

Exposure to environmental noise affects health through complex psychological and physiological pathways (Babisch, 2002) and it has been linked to a number of health outcomes, such as cardiovascular and metabolic effects, poor sleep and annoyance in adults, as well as to cognitive impairment in children (WHO Europe, 2018a). Possible explanations for the most severe effects of noise on health, such as those on the heart and circulatory system, are stress and a decrease in sleep quality (van Kempen et al., 2018). According to the WHO, the DALYs (see Box 2.1) lost because of noise-induced health outcomes in the western part of Europe are estimated to be equivalent to 903 000 years for sleep disturbance, 654 000 years

Figure 2.2 Years of life lost per 100 000 inhabitants attributable to noise in 30 European capitals (2011)



Note: For capitals of the EU-27 countries (excluding Slovenia) plus Iceland, Norway and Switzerland. Based on non-gap filled data.

Source: Based on ETC/ACM (2018b).

for annoyance, 61 000 years for ischaemic heart disease and 45 000 years for cognitive impairment in children (Jarosińska et al., 2018). It is estimated that noise could contribute to 16 600 premature deaths per year; about two thirds of the burden of disease is related to coronary heart disease and one third to cerebrovascular disease (ETC/ACM, 2017). The analysis carried out for 30 European capitals (Figure 2.2) shows that the highest number of YLL per 100 000 inhabitants attributable to noise occurs in the new Member States in eastern Europe.

2.3.2 Impacts on vulnerable groups

In comparison with air pollution, fewer studies have investigated social inequalities in the context of exposure to environmental noise and its impacts, and most have focused on impacts on children (EC, 2016b). Noise particularly affects children's cognitive performance; according to a review commissioned by WHO, aircraft noise has been shown to impair the reading and oral comprehension of children attending schools that are affected by aircraft paths (Clark and Paunovic, 2018). Although WHO only found a link between cognitive effects on children and aircraft noise, it is possible that other transport sources affect children in the same way. For instance, a recent study in Norway suggested that road traffic noise has a negative impact on children's attention (Weyde et al., 2017).

Children's noise annoyance differs from that of adults, although research in this area is limited. Two studies suggest that children are more annoyed by low levels of noise and less annoyed by high noise levels than adults (van Kempen et al., 2009; Lercher et al., 2000). In one study, German school children were less frequently annoyed by road traffic noise at home than adults (Babisch et al., 2012). However, factors such as bedroom location, socio-economic status and residential satisfaction may modify children's response to noise (Grelat et al., 2016).

Children are more sensitive than adults to the physiological effects of noise during sleep, such as blood pressure reactions (Babisch et al., 2009; van Kempen, 2006; van Kamp and Davies, 2013), but the quality of the evidence is relatively low (van Kempen et al., 2018). In contrast, children seem to be less sensitive to awakenings and sleep cycle shifts (van Kamp and Davies, 2013). Mental health may decrease in schoolchildren and young adults as a result of the annoyance caused by exposure to noise, as suggested by a Bulgarian study (Dzhambov et al., 2017).

The elderly, in general, are not disproportionately impacted by noise (van Kamp and Davies, 2013). In fact, noise has been found to affect the middle age ranges more, as far as annoyance and disturbance are concerned (Van Gerven et al., 2009). However, the elderly may be more prone to cardiovascular effects as a result of noise. For instance, a study in Madrid found that higher noise levels were linked to a higher risk of cardiovascular mortality in people aged over 64 years old (Tobias et al., 2014).

Other groups potentially vulnerable to noise are shift-workers, noise-sensitive people and people with certain pre-existing health conditions, such as people with sleeping or mental disorders. People suffering from chronic diseases were found to have a slightly higher cardiovascular risk due to noise than those without such pre-existing conditions (van Kamp and Davies, 2013; Eriksson et al., 2010). An increased number of negative effects of noise on sleep was observed among shift workers who sleep during the day (Muzet, 2007). People considered to be noise sensitive are generally more susceptible to sleep disturbance, as well as to psychological and cardiovascular effects due to noise (Marks and Griefahn, 2007; Berry and Flindell, 2009; Stansfeld, 1992).

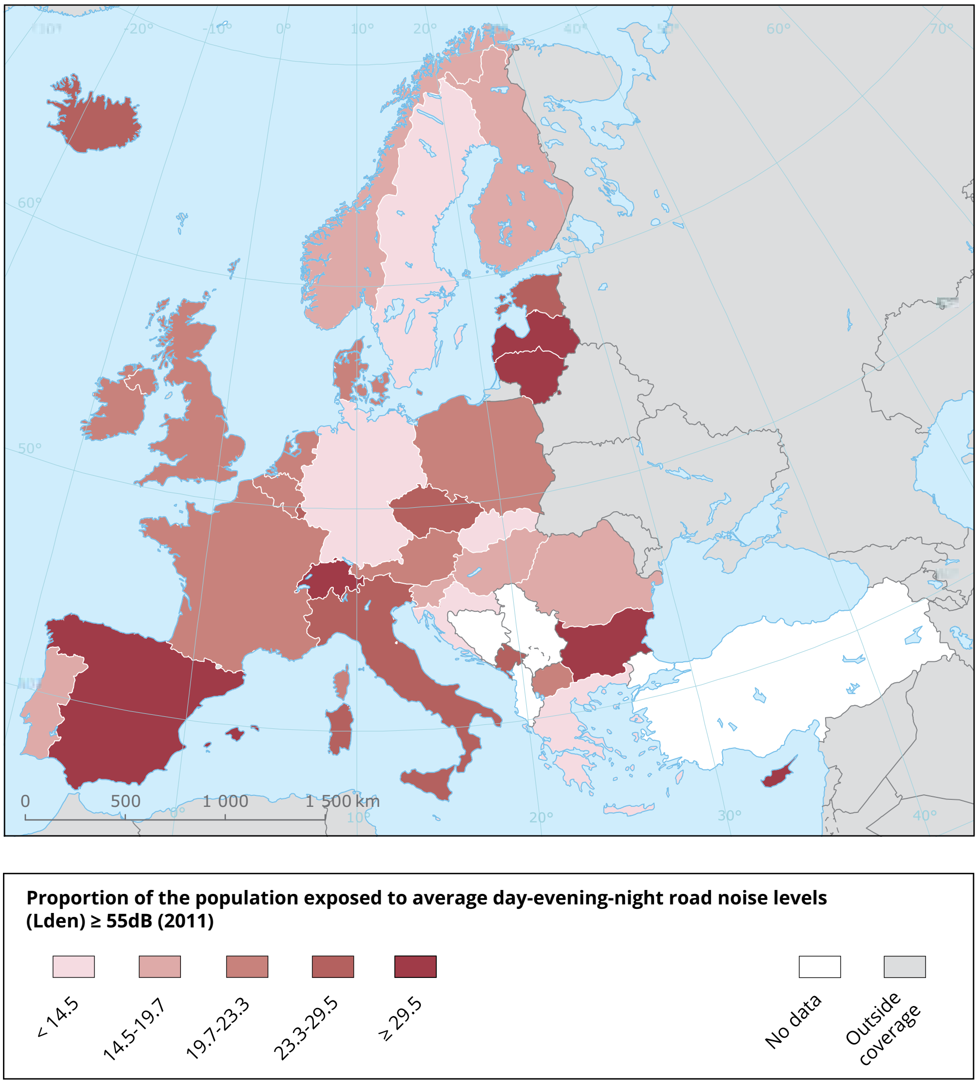
The health of those of lower socio-economic status can be disproportionately affected by noise. In Maastricht, the Netherlands, greater exposure to road and rail noise was linked to increased depressive symptoms in groups of lower educational achievement (Putrik et al., 2015). In addition, low socio-economic status, in combination with neighbourhood noise and traffic noise, was linked to an increased risk of death from heart disease for men (Kamphuis et al., 2013). In the United Kingdom, self-reported sleep problems due to multiple contributing factors including neighbourhood noise were worse in people from lower socio-economic status groups (Arber et al., 2009). However, in a Swiss study, no direct link was found between socio-economic status and the risk of dying from a heart attack in areas exposed to aircraft noise — the main factor increasing the risk of death was the length of residence in an area characterised by high levels of noise (Huss et al., 2010).

2.3.3 Exposure of vulnerable groups to noise

In general, lower socio-economic groups tend to be exposed to higher levels of noise, in particular road traffic noise; lower socio-economic status has been linked to exposure to road noise in studies from several European countries, e.g. Germany (Kohlhuber et al., 2006; Hoffmann et al., 2003; Laußmann et al., 2013; Bolte and Fromme, 2008), Switzerland (Braun-Fahrländer et al., 2004) and the Netherlands (Kruize and Bouwman, 2004). In addition, a study on inequalities regarding access to quiet areas (established in response to the Environmental Noise Directive, 2002/49/EC) in the city of Southampton, United Kingdom indicated that those living in more deprived locations had less access to quiet areas (Battaner-Moro et al., 2010). However, the results seem to depend highly on the socio-economic indicator used, the location of the study and the noise source (Lakes and Brückner, 2011). For example, a more mixed picture emerges when looking at noise associated with different forms of transport. In London, an increase in all domains of deprivation considered in the national Index of Multiple Deprivation was associated with higher levels of road traffic, rail traffic and aircraft noise (Fecht et al., 2017). In a study from the Dutch Rijnmond region, exposure to higher levels of rail traffic noise was associated with low income areas; however, increased exposure to aircraft noise was associated with high income areas (Kruize, 2007). Likewise, in London, it was found that groups with the most area-level income deprivation were most likely to be exposed to rail noise (Tonne et al., 2018). Among the schools located near Heathrow Airport in the United Kingdom, those with a higher proportion of students from poorer backgrounds had higher noise exposure (Haines et al., 2002). In relation to industrial noise, Swiss data show that 65 % of households with the lowest socio-economic status are located in areas with industrial activities where background noise levels are around 7 dB(A) higher than in industry-free residential areas, occupied by groups of higher socio-economic status (Braun-Fahrländer et al., 2004).

However, the connection between noise exposure and socio-economic status is not always present. At the country level, there seems to be no clear regional differentiation across Europe (see Map 2.2). Looking at different income groups within individual countries, (i.e. in Croatia, Greece, Poland and Romania), people at risk of poverty in 2016 were less likely than the general population to be subjected to noise from neighbours or the street. This is because a significant proportion of people at risk of poverty in those countries are living in rural, and thus quieter, areas. By contrast, in western Member States, the poverty is more concentrated in cities and this may explain, to some degree, why in Belgium, Denmark, France, Germany, Luxembourg and the Netherlands the proportion of the population reporting noise from the street or from neighbours is higher among people at risk of poverty than the average for the whole population (Eurostat, 2018b). Furthermore, in certain locations, those from more affluent social groups may choose to live in areas affected by noise, for example in the city centre of Paris (Havard et al., 2011) or in a prestigious area located close to a large airport (Tonne et al., 2018). In many locations, no clear relationship was found between socio-economic status and exposure to noise — for example, in Marseille (Bocquier et al., 2013), in Oslo (Fyhri and Klæboe, 2006) and in Berlin, Germany (Lakes and Brückner, 2011). Therefore, socio-economic status cannot be used to predict exposure to noise, even if, in many places, people of lower socio-economic status live in areas with higher levels of noise.

Map 2.2 **Proportion of the population exposed to average day-evening-night road noise levels (Lden)>= 55dB (2011)**



Note: For EU-28 countries, plus the former Yugoslav Republic of Macedonia, Iceland, Norway and Switzerland. Because of gaps in the reported data, a gap-filling routine is used to estimate the total population exposure to high noise levels.

Source: EEA based on data officially reported by countries under the EU Environmental Noise Directive (2002/49/EC; EU, 2002).

2.4 Extreme temperatures: impacts and exposure

2.4.1 Impacts of extreme temperatures on European citizens

Fatalities related to cold and heat

During the period 1980-2016, climate- and weather-related events caused nearly 90 000 additional deaths across the 33 EEA member countries ([6]) (EEA, 2018b). Most of the fatalities (87 %) were associated with heatwave events, i.e. periods of hot weather lasting for several days. This large percentage of fatalities was highly influenced by the heatwave of 2003, where around 70 000 fatalities were reported as excess mortality across Europe (Robine et al., 2008). More recently, the 2015 heatwave caused more than 3 000 additional deaths in France alone (CRED, 2016). The effects of exposure can be directly related to heat (heat stroke, heat fatigue and dehydration, or heat stress) or can be the result of a worsening of respiratory and cardiovascular diseases, electrolyte disorders and kidney problems (Åström et al., 2013; Analitis et al., 2014; Breitner et al., 2014). The fatalities associated with heatwaves in Europe tend to be concentrated in southern and south-western Europe, whereas northern and north-eastern Europe are less affected (Map 2.3, left), largely because of the geographic distribution of temperatures across Europe.

In comparison with heatwaves, cold-related mortality is much less investigated, although rates of excess mortality are higher for most European countries during winter than during summer (Mercer, 2003; Almendra et al., 2017). Mortality due to cold is mainly caused by arterial thrombosis as a result of cold-induced haemo-concentration and hypertension, as well as respiratory disease attributable to infectious disease (Oudin Åström et al., 2013). The immediate victims of cold temperatures tend to be people exposed to the elements or having inadequate shelter (Poljanšek et al., 2017). The Centre for Research on the Epidemiology of Disasters (CRED) reports just over 3 500 cold-weather related fatalities during the period 1990-2016. In contrast to heatwaves, fatalities associated with cold temperatures tend to be concentrated in the east of Europe (Map 2.3, right).

While the effects of heat occur mostly on the same day and in the following 3 days, the effects of cold on health are greatest 2-3 weeks after the event (Healy, 2003; Analitis et al., 2008; WHO Europe, 2011; Ye et al., 2012). In addition, exposure to persistent levels of moderately low temperatures at home seems to have a more significant impact on health than short periods of extremely low temperatures, which have been found to be a marginal contributor to overall winter mortality (Ebi and Mills, 2013). As people spend approximately 80 % of their time indoors (Poljanšek et al., 2017), living in cold housing contributes substantially to excess winter deaths (see Box 2.1), which are mainly attributable to cardiovascular and respiratory diseases (WHO Europe, 2012). Non-fatal cardiovascular and respiratory diseases are also linked to low indoor temperatures, which exacerbate existing conditions, such as arthritis and rheumatism, increased blood pressure and the risk of stroke, and are linked to pneumonia, asthma, bronchitis, influenza, heart diseases and migraines, as well as depression and anxiety (WHO Europe, 2012; Santamouris et al., 2014), all of which lower quality of life and put a strain on public health systems.

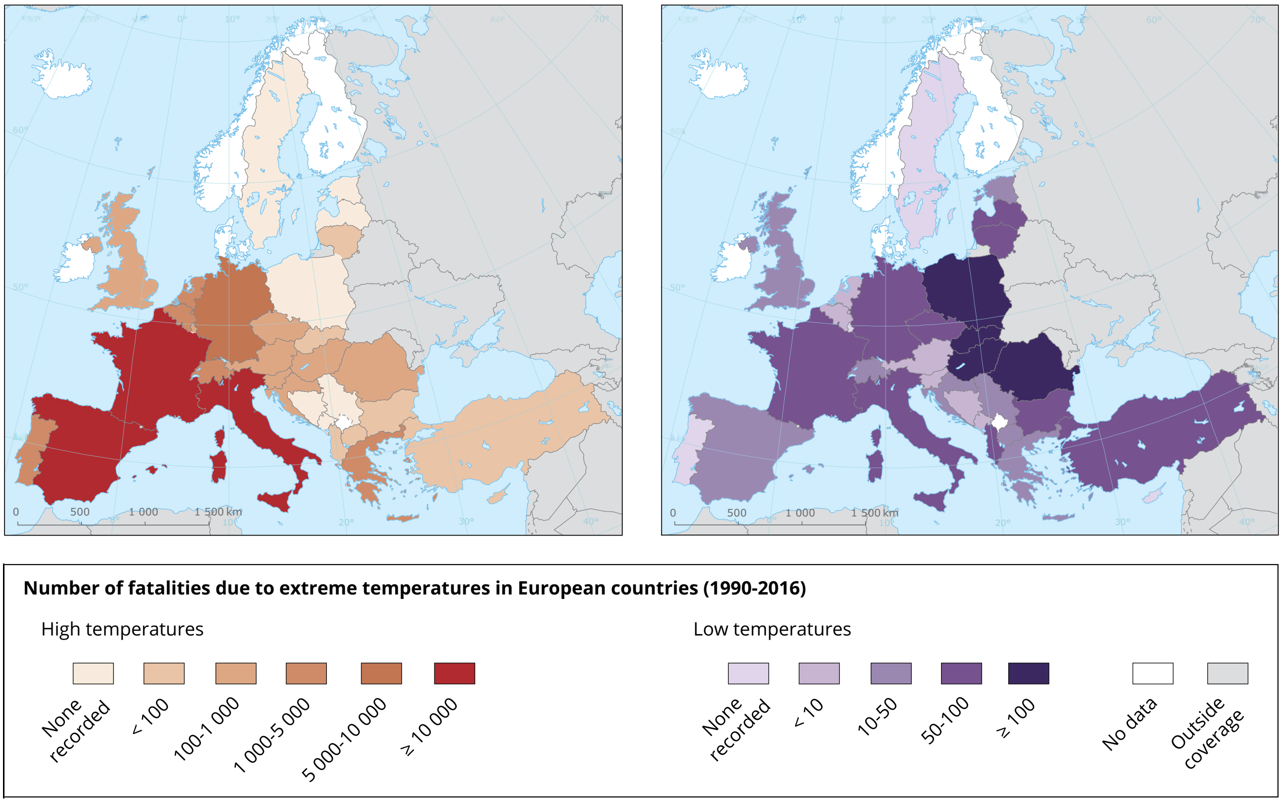
The number of excess winter deaths in Europe is much higher than the number of fatalities linked to extremely low temperatures. Mortality rates for decreasing temperatures tend to be higher in warmer countries than in cold ones (Ebi and Mills, 2013). Studies suggest that winter mortality is higher in Greece, Italy, Portugal and Spain than in Finland, Germany and the Netherlands (Healy, 2003; Carmona et al., 2016). Conversely, in many countries with colder climates, excess winter deaths are less pronounced or absent; in the Netherlands and Finland, cold spells were observed as having weaker impacts on mortality than heatwaves (Ekamper et al., 2009; Ruuhela et al., 2017). This can be linked to a number of factors, from housing quality and availability of affordable heating to acclimatisation of people to lower temperatures.

2.4.2 Impacts of heat and cold on vulnerable groups

Age, pre-existing medical conditions and social deprivation are the key factors that make people experience more adverse health outcomes related to extreme temperatures (Paavola, 2017). In particular, old age exacerbates negative health outcomes of heat stress (Josseran et al., 2009) and, in various European countries, older people tend to be the most likely victims of heatwaves (Hajat et al., 2007; Canoui-Poitrine et al., 2006; Urban et al., 2017; Gabriel and Endlicher, 2011). For example, mortality among the elderly during heatwaves in England (in 2003) and Finland (in 2003 and 2010) increased by over 20 % (Johnson et al., 2005; Kollanus and Lanki, 2014).

([6]) https://www.eea.europa.eu/countries-and-regions

Map 2.3 Number of fatalities due to extreme temperatures in European countries (1990-2016)



Note: For an event to be included in EM-DAT, at least one of the following criteria needs to be met: (1) 10 or more people killed; (2) 100 or more people affected; (3) declaration of a state of emergency; (4) call for international assistance (CRED, 2018). Therefore, the maps may not provide a complete number of fatalities linked to extreme temperatures. The number of heat-related fatalities during the period 1990-2016 was heavily affected by the heatwave of 2003. The number of cold-related fatalities includes both victims of 'cold waves' and 'extreme winter conditions'.

Source: EM-DAT: The Emergency Events Database, Université catholique de Louvain (UCL), CRED, D. Guha-Sapir, Brussels, Belgium, https:// www.emdat.be (accessed 18 February 2018).

In addition, the elderly are potentially more susceptible to the effects of cold spells than other age groups (Ryti et al., 2015); higher excess winter mortality among the elderly has been found in the United Kingdom and the Netherlands (Maheswaran et al., 2004; Ekamper et al., 2009). However, in the Helsinki region, only a slight increase in excess winter mortality was found for the elderly, and only at very low temperature values (Ruuhela et al., 2017).

Children, especially those with illnesses such as diarrhoea, respiratory tract infections and neurological defects are particularly at risk of heat stress (McGeehin and Mirabelli, 2001). In relation to low temperatures, living in cold homes puts children at risk of respiratory problems associated with the development of moulds (WHO Europe, 2012). Children and adolescents are at the highest risk of mental health problems and social isolation as a result of cold housing, which, in turn, may negatively affect their learning abilities (Marmot et al., 2010; Shortt and Rugkåsa, 2007).

Those with chronic diseases also have a heightened risk of heat-related mortality (Wolf et al., 2015). Electrolyte imbalances, cardiovascular and respiratory diseases, diabetes and renal problems can affect the body's ability to sweat and regulate its temperature. Other conditions that affect an individual's ability to adapt their behaviour to keep cool include nervous system disorders, having a disability and being bed bound, thus unable to care for themselves (Semenza et al., 1999). Heatwaves also significantly increase morbidity and mortality among those with chronic lung disease (Jehn et al., 2013). Furthermore, mental health illnesses have also been found to increase high temperature-related mortality (Hajat et al., 2007; Kaiser et al., 2001). People with cardiovascular and respiratory diseases tend to be more affected by cold spells (Ryti et al., 2015; Wilkinson et al., 2004).

Socio-economic status is linked to excess winter deaths. The homeless are much more likely (even six to ten times more likely) to die from hypothermia than the general population, even in moderate cold stress conditions (Vuillermoz et al., 2016; Romaszko et al., 2017). In addition, inadequate housing conditions (see also Section 2.1.2) and the ability of more deprived people to afford heating affect their exposure to cold. Countries with high levels of income poverty and inequality (Greece, Ireland, Portugal) demonstrate the highest rates of seasonal variation in mortality (Healy, 2003). In Portugal, municipalities with higher socio-economic deprivation levels experienced higher excess winter mortality than places with lower levels of deprivation (Almendra et al., 2017). However, in the United Kingdom, several studies did not find the expected relationships between poverty, inadequate home heating and health during the winter (Curtis et al., 2017; Hajat et al., 2007; Hajat, 2017); this may be due to many of the poorest households living in social housing, which often has higher thermal efficiency than private housing (Wilkinson et al., 2004).

Socio-economic status also influences the risk of heat-related mortality (Wolf et al., 2015; Fernandez Milan and Creutzig, 2015; Arbuthnott and Hajat, 2017). A link was found between heatwave-related morbidity or mortality and the levels of unemployment in Mediterranean cities (Leone et al., 2013) and low levels of education in Czechia (Urban et al., 2016).

In addition to socio-economic status, age and health, social isolation increases the risk of death as a result of extreme weather events. Generally, people living on their own tend to be more vulnerable during heatwaves (McGeehin and Mirabelli, 2001); 92 % of the 2003 heatwave victims in France lived alone (Poumadère et al., 2005). Those with more extensive social networks were found to experience lower heat stress than those with no-one to rely on (Seebaß, 2017).

2.4.3 Exposure of vulnerable groups to extreme temperatures

In comparison with air pollution and noise, the spatial differences in temperature generally occur at larger spatial scales. The differences in people's exposure to high and low temperatures within cities or regions are largely driven by the quality of their living environment. The UHI effect causes the temperatures in cities to be higher than in surrounding rural areas (see Section 2.1.2). At the level of individual buildings or households, people's exposure to extreme temperatures is influenced by their ability to maintain comfortable temperatures in their homes. This, in turn, depends on the type and quality of housing (see also Section 2.1.2) and the ability of people to afford artificial cooling or heating.

Exposure to heat in cities

The temperatures in European city centres can be higher than in surrounding areas by up to 9 °C (Tzavali et al., 2015). Generally, northern European cities seem to develop stronger UHIs, whereas differences between urban and rural temperatures appear to be lower in southern European cities (Ward et al., 2016). As a consequence of the UHI, urban areas may experience twice as many heatwave days compared with their rural surroundings (Hooyberghs et al., 2015).

Generally, in many European countries, more vulnerable communities tend to live in dense, urban environments ([7]) (see Section 2.1.2) and, therefore, may be exposed to higher temperatures. In locations such as Rennes, France, and Birmingham, United Kingdom, city centres are characterised by high proportions of the elderly, people in poor health and those living alone. They also have the highest intensity of UHIs (Buscail et al., 2012; Tomlinson et al., 2011). In London and Greater Manchester, United Kingdom, poorer communities are more likely to live within UHIs (Wolf and McGregor, 2013; Kazmierczak, 2012). In addition, analyses of the distribution of facilities for vulnerable groups, such as hospitals, care homes and schools, found that they were predominantly located in areas up to 2 °C warmer than the regional average (Macintyre et al., 2018; Kazmierczak, 2012). However, as highlighted in Section 2.2 regarding air pollution, more affluent people are living centrally in some cities, and thus are potentially more exposed to UHIs.

Less is known about the influence of UHIs on mortality related to low temperatures. In England and Wales, cold-related mortality was higher for more deprived populations in rural settings, while no such relationship was observed in cities (Hajat et al., 2007). It is suggested that in the cities, which experience low temperatures during winter, UHIs may bring positive effects for

([7]) However, in Croatia, Greece, Poland and Romania a relatively high proportion of people at risk of poverty are living in rural areas (Eurostat, 2015).

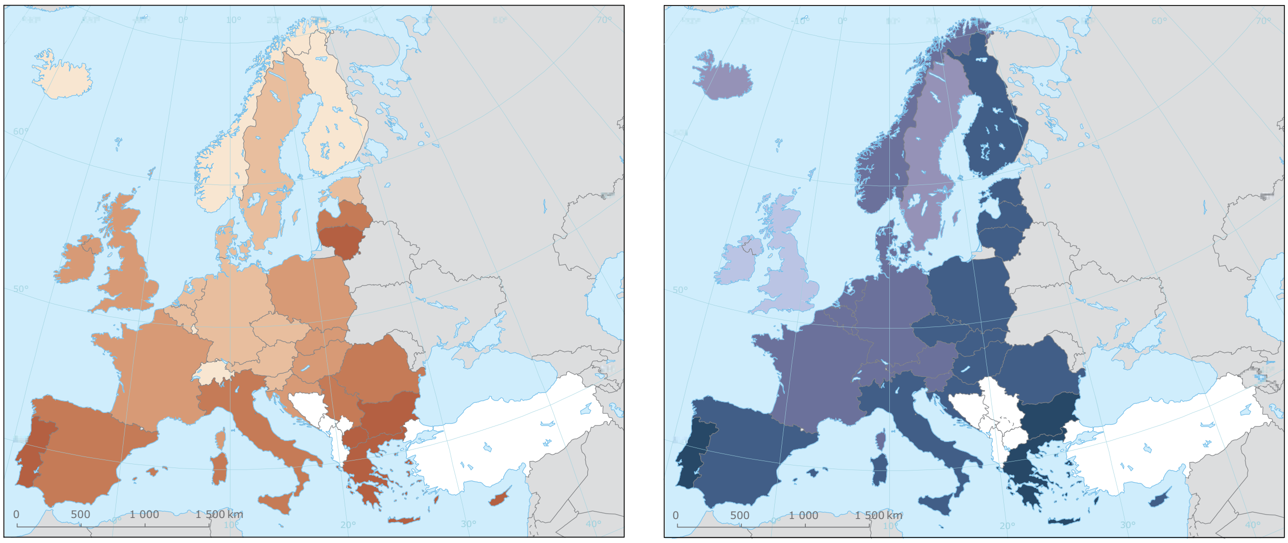
human health by increasing temperatures and consequently creating a warmer environment than in the surrounding areas (Poljanšek et al., 2017).

Ability to keep homes at a comfortable temperature throughout the year

According to Eurostat statistics on income and living conditions (EU-SILC), nearly 10 % of households in 33 European countries ([8]) in 2016 were unable to keep their homes warm during winter. Among households below the at-risk-of-poverty threshold, i.e. those below 60 % of median equivalised income, nearly one fifth were unable to keep their homes warm. Over 20 % of the general population in 31 European countries ([9]) were unable to keep their house cool during summer; one quarter of the population in the bottom 20 % of household income lived in homes difficult to keep cool during summer (Eurostat, 2016).

The percentage of people able to maintain comfortable temperatures in their homes varies from country to country (Map 2.4). Generally, the lowest proportion of households able to keep their homes warm is found in the east and the south of Europe; in Bulgaria, nearly 40 % of all households struggle to keep warm in winter. This may explain why excess winter mortality in southern European countries is higher than in northern European countries (EEA, 2017). There is a similar distribution regarding the number of people living in uncomfortably warm houses during summer, with Bulgaria, Portugal, Malta and Greece having the highest proportion of people potentially affected by high temperatures. WHO Europe (2012) links the discrepancies in people's ability to keep homes at comfortable temperatures to energy poverty, associated with both low income and poor energy efficiency of housing.

Map 2.4 Percentage of households unable to keep their home warm during winter (2016; left) and percentage of population living in a dwelling not comfortably cool during summer (2012; right)



Percentage of households unable to keep their home warm in winter (2016; left) and share of population living in a dwelling not comfortably cool in summer (2012; right)

% < 2 | 2-5 | 5-10 | 10-20 | ≥ 20

% < 5 | 5-10 | 10-20 | 20-30 | ≥ 30 | No data | Outside coverage

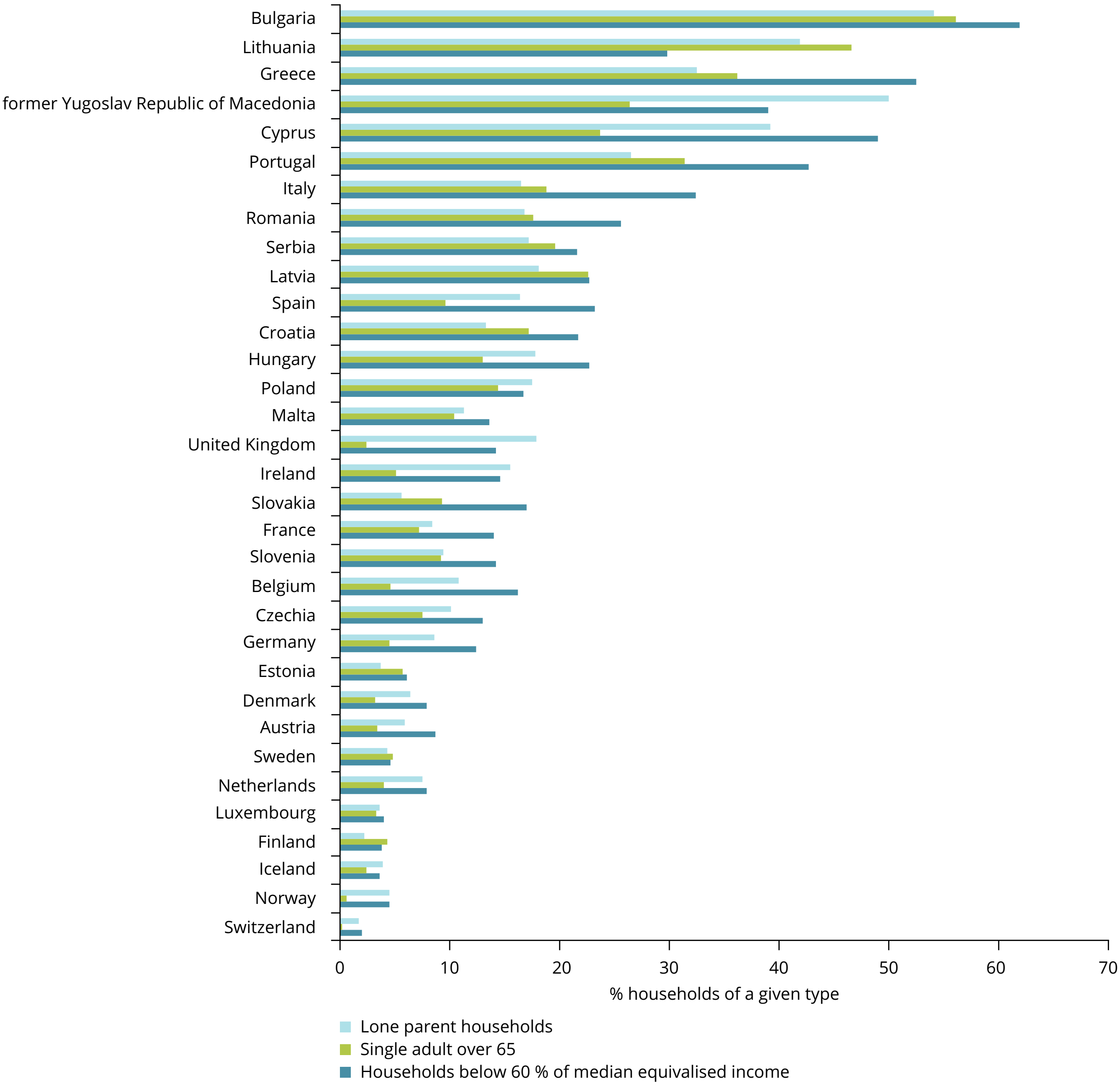
Note: Countries covered in the left-hand side map include EU-28 and the former Yugoslav Republic of Macedonia, Iceland, Norway, Serbia and Switzerland. Countries covered in the right-hand side map include EU-28 and Iceland, Norway and Switzerland.

Source: EU-SILC 2012 and 2016 (Eurostat, 2016).

([8]) EU-28 and the former Yugoslav Republic of Macedonia, Iceland, Norway, Serbia and Switzerland.
([9]) EU-28 and Iceland, Norway and Switzerland.

Taking into account the different types of vulnerable households (Figure 2.3), for most countries, households below the poverty threshold are the least able to keep warm during winter; over half of the poorest households in Bulgaria and Greece struggle to keep their homes warm. However, in Lithuania, for example, it is the single older adult households that are the most frequently at risk of living in a cold home, and in the former Yugoslav Republic of Macedonia, Poland and the United Kingdom, lone parent households emerge as the type of vulnerable household that is most frequently unable to keep their homes warm. This emphasises the localised character of vulnerability and exposure, as well as the need for careful identification of who is the most vulnerable, in order to design and prioritise appropriate responses (see also Section 5.3).

Figure 2.3 **Percentage of vulnerable households in European countries unable to keep their homes warm during winter (2016)**

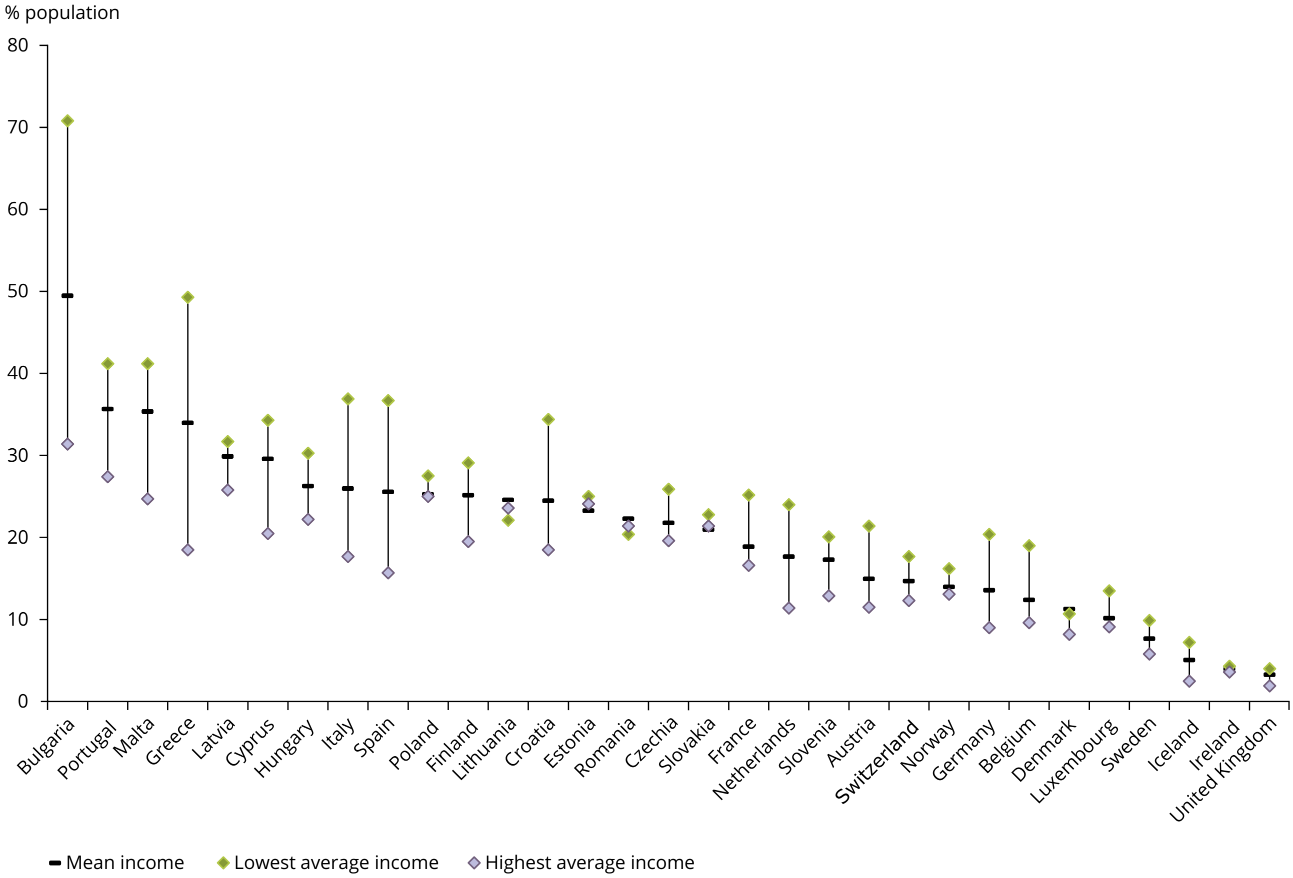


Note: The countries are presented in descending order, taking into account the highest overall percentage of households unable to keep warm in winter.

Source: EU-SILC 2016 (Eurostat, 2016).

In all countries (except Lithuania), households with an income in the bottom 20 % were less able to keep their homes cool during summer than the rest of the population (Figure 2.4). The discrepancies in the percentages of people living in uncomfortably warm dwellings are greatest in the case of Bulgaria, Greece, Spain and Italy. It is important to observe that the proportion of the general European population unable to keep their dwelling comfortably cool during summer is higher than the proportion unable to keep their home warm during winter (WHO Europe, 2012), indicating that summer temperatures may be a rising problem in the future under the changing climate (see also Section 6.1).

Figure 2.4 Proportion of the European population living in a dwelling not comfortably cool during summer (2012)



Note: The countries are presented in descending order, taking into account the highest proportion of the population living in homes not comfortably cool during summer. The lowest average income refers to the average income in the bottom 20 %; the highest average income refers to the average income in the top 20 %.

Source: EU-SILC 2012 (Eurostat, 2016).

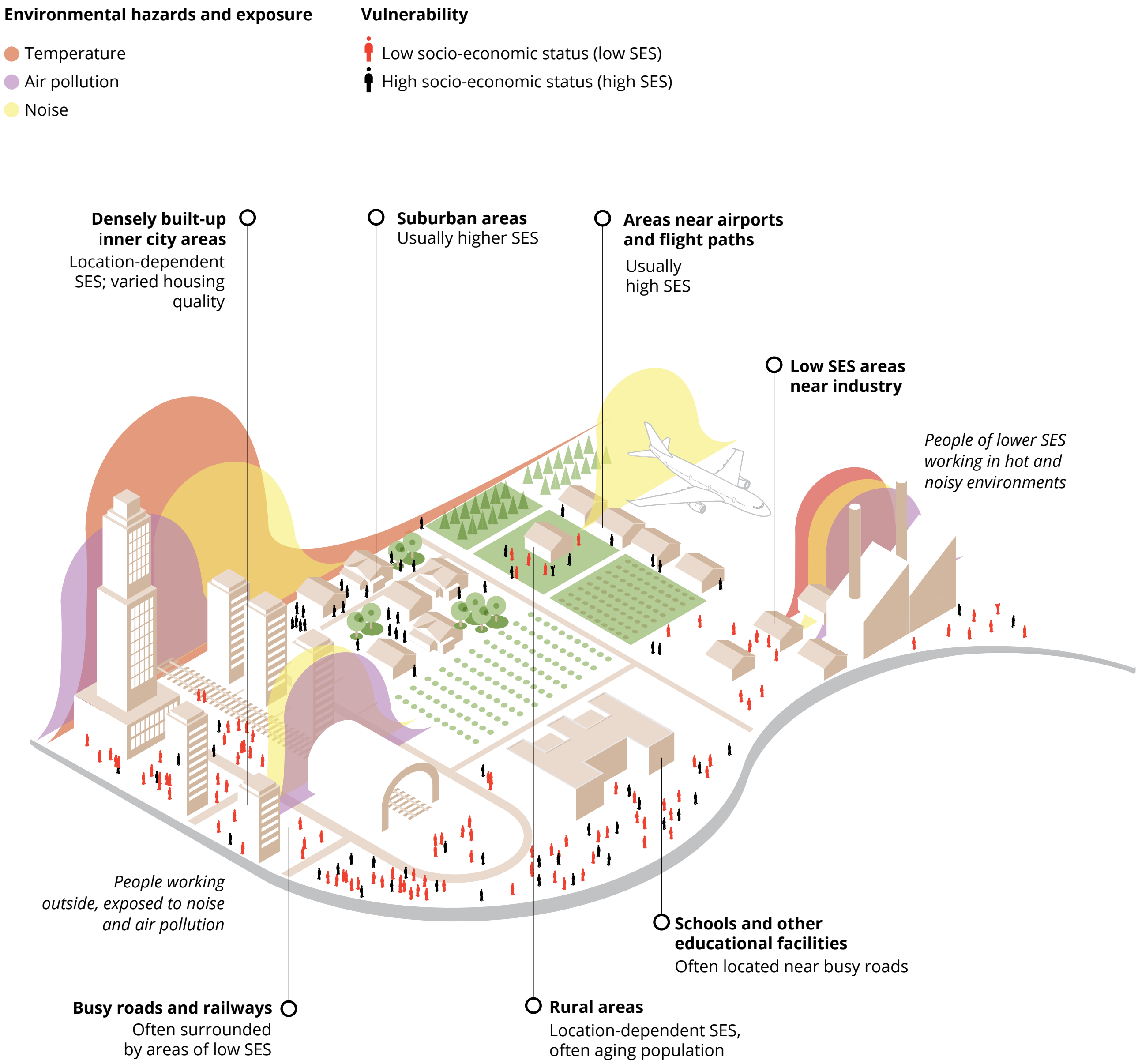
2.5 Impacts of multiple hazards on vulnerable groups

The earlier parts of this chapter identified that vulnerability is mainly driven by individual characteristics (age and health), although social factors, such as the extent of social support networks, also affect vulnerability. There is a clear link between socio-economic status and exposure through the type of environment that low-income groups live in, the quality of housing and, to a lesser degree, their occupation. The evidence review indicates that the impacts of air pollution, noise and extreme temperatures occur as a combination of vulnerability and exposure to hazards. Figure 2.5 summarises the exposure of vulnerable groups to air pollution, noise and extreme temperatures.

The evidence review suggests that it is often a combination of factors, e.g. advanced age combined with low socio-economic status, or pre-existing health conditions combined with city-centre living, that intensify the impacts of environmental health hazards on vulnerable people. However, less is known about the cumulative impact of different hazards on human health. Air pollution and noise share some sources, such as road traffic and industrial activities, and their effects are in some cases difficult to disentangle. In cities in particular, people exposed to air pollution tend to be exposed to noise as well (see also Figure 2.5). The health effects of both types of stressors are similar (see Sections 2.2 and 2.3) and can therefore have a synergistic effect on human health. The combined health impact of road traffic noise and air pollution estimated across 497 European agglomerations is, on average, 1 745 DALYs per year per 100 000 inhabitants. This corresponds to 6.2 % of the total burden of disease for all causes per year (ETC/ACM, 2018b).

The best investigated cumulative effect is that of air pollution and high temperatures. During hot weather, synergistic effects between high temperature and air pollution (PM_{10} and O_3) can be observed, leading to increased morbidity and mortality (Katsouyanni and Analitis, 2009; Burkart et al., 2013; De Sario et al., 2013; Macintyre et al., 2018). An investigation into the association between residential proximity to roads and low birth weight found that air pollution and heat exposures together explained about one third of this association (Dadvand et al., 2014). However, a study in Cyprus did not find that there was a significant impact of the PM_{10} concentrations on temperature-related mortality (Heaviside et al., 2016b). In relation to cold temperatures, the combination of PM_{10} pollution and low temperatures increased morbidity for myocardial infarction in two provinces of Portugal (Vasconcelos et al., 2013).

Figure 2.5 Exposure of vulnerable groups to air pollution, noise and extreme temperatures



Source: EEA

3 Exploratory pan-European assessment of vulnerable regions' exposure to environmental health hazards

Key messages

- Generally, nomenclature of territorial units for statistics (NUTS) 2 regions characterised by lower socio-economic status tended to have higher levels of $PM_{2.5}$, PM_{10} and O_3 pollution. However, for NO_2, the opposite was found — NUTS 2 regions with higher socio-economic status generally experienced higher levels of NO_2 pollution. The scale of analysis may mask differences within regions.
- The strongest associations were found between low socio-economic status and exposure to PM_{10}, with both relatively poor and polluted regions occurring in central, eastern and south-eastern parts of Europe.
- The regions with the lowest proportion of people with tertiary education overlap with high exposure to O_3. This is due to the two phenomena concentrating in southern parts of Europe and there is no causal relationship.
- Generally, the associations between noise exposure and social vulnerability on a regional scale were found to be weak. This may have been caused by the high spatial variability of noise, which was not captured in this assessment on account of the size of spatial units or the low noise threshold used, not distinguishing areas severely affected by noise. Nonetheless, people living in NUTS 2 regions characterised by lower income levels and in cities with high levels of unemployment tend to experience higher levels of noise.
- The NUTS regions with low GDP, a high proportion of people of low socio-economic status and a high percentage of elderly people overlap with areas affected by high temperatures.
- Multiple hazards and multiple causes of vulnerability tend to overlap in regions in southern and south-eastern Europe.

3.1 Introduction

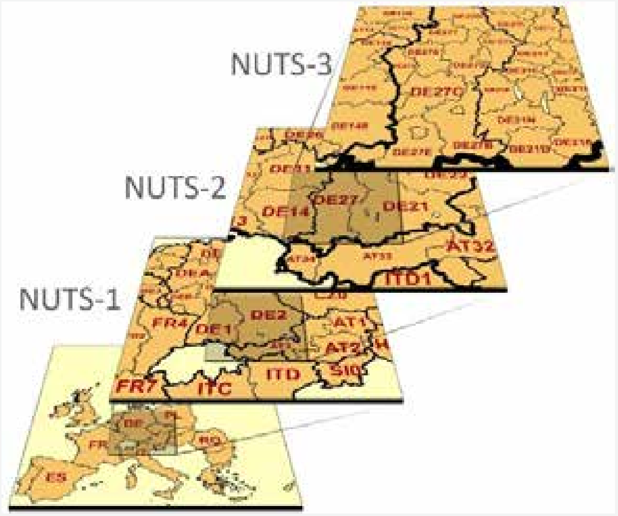
3.1.1 Scales of assessment

Social and environmental inequalities exist at both local and European scales and analysing environmental inequalities in relation to the socio-economic situation is most reliable if it is done at various spatial scales (Mennis, 2002; EC, 2016b). The previous chapter provided an overview of the evidence linking socio-economic status and age to the impacts of and exposure to air pollution, noise and extreme temperatures at different spatial scales within countries, regions, individual cities or at human group and individual level. Studies at fine spatial scales help to understand the local situation and are thus a useful source of information for local decision-makers. However, because they are location specific they do not provide a comprehensive overview of the associations between social vulnerability and environmental health hazards in Europe. At the same time, country-level analyses, such as those offered by Eurostat in relation to quality of life indicators (Eurostat, 2015a), or the data on fatalities associated with temperatures (presented in Map 2.3) offer European coverage but at a very coarse scale. A previous pan-European study investigating the links between air pollution levels and GDP per capita at NUTS 3 level (CRESH, 2013) was limited to economic aspects of vulnerability. Therefore, to facilitate a discussion on the inequalities among various groups in terms of exposure to environmental health hazards across Europe, a consistent assessment is needed on a sub-national scale.

This chapter describes the results of the exploratory pan-European assessment carried out at the level of sub-national statistical units and cities (see Box 3.1). This assessment aimed to explore variations in exposure and social vulnerability. It did not assess the differences in pollution exposure and social indicators that occur between small neighbourhoods in different parts of cities, so the findings cannot be extrapolated to patterns within individual regions or cities (see also Box 3.4 further on in the chapter).

Box 3.1 Spatial units used in the pan-European assessment of exposure

NUTS (French *Nomenclature des unités territoriales statistiques*) is a hierarchical system for dividing up the economic territory of the EU for the purpose of collecting, developing and harmonising European statistics, socio-economic analyses of the regions and framing EU policies. This report uses two levels of NUTS (2013 classification):



NUTS 2 are areas of 800 000-1 500 000 inhabitants. In 2013, there were 276 NUTS 2 units in the EU-28 countries, ranging from below 13 km² in size (Ciudad Autónoma de Melilla, Spain) to 226 785 km² (Pohjois- ja Itä-Suomi, Finland). NUTS 2 regions are basic regions for the application of EU regional policies.

NUTS 2 are split into **NUTS 3**, which are areas of 150 000-800 000 inhabitants. There were 1 342 NUTS 3 units in the EU-28 countries, the largest being Norrbottens län in Sweden (105 205 km²) and the smallest (same as NUTS 2) Melilla. NUTS 3 are small regions used for specific diagnoses.

NUTS 2 and NUTS 3 regions correspond with different levels of administration, depending on the Member State. For example, in Germany, NUTS 2 are government regions (*Regierungsbezirke*) and NUTS 3 are districts (*Kreise*), while in France, NUTS 2 are Régions and NUTS 3 are *Départements*. In the case of some smaller countries, such as Cyprus or Luxembourg, the whole country is one NUTS 2/NUTS 3 area.

The third type of spatial units used in the pan-European assessment in this report were cities included in the **Urban Audit** (City Statistics). Urban Audit provided data sets relating to various aspects of quality of life in cities within the EU, Norway and Switzerland. Data availability differs depending on topic and year, as the statistics are provided by countries on a voluntary basis. This report uses the statistics at a city (formerly core city) level.

Sources: Eurostat (2015b, 2017a).

3.1.2 *Analysing distribution of environmental health hazards by regional vulnerability level*

The assessment considers the following aspects of vulnerability:

- age-related, i.e. proportions of elderly people and young children in the population due to the heightened susceptibility of these groups to harm from the majority of hazards considered in this report (with a possible exception of noise, see Chapter 2);
- socio-economic status, approximated by indicators of income, unemployment levels and educational attainment of the population (Grundy and Holt, 2001; Duncan et al., 2002; Tajik and Majdzadeh, 2014; Hobza et al., 2017), which affects vulnerability and also influences exposure through inability to pay to live in a higher quality environment or in better housing and through occupation or commuting (see Section 2.1.2).

It is challenging to identify indicators that reflect social vulnerability to health risks posed by air pollution, noise and extreme temperatures and that, at the same time, are consistently available for all — or most — European countries in NUTS 3 or NUTS 2 regions or Urban Audit cities. This has effectively limited the indicators to those sourced from Eurostat (Table 3.1).

Table 3.1 Indicators of social vulnerability used in the pan-European assessment of exposure to air pollution, noise and extreme temperatures

	Spatial unit		
	NUTS 2 (2013-2014) (a)	**NUTS 3 (2013-2014) (a)**	**Urban Audit cities (2011-2012) (a)**
Age	Percentage of young children (under 5 years old) in population	-	Percentage of young children (under 5 years old) in population
	Percentage of elderly people (75 years old or older) in population	-	Percentage of elderly people (75 years old or older) in population
Socio-economic status	Household income (per capita after social transfers, purchasing power standard (euros))	Per capita GDP, purchasing power standard (euros) (b)	-
	Long-term unemployment rate (12 months or more; percentage of economically active population)	-	Unemployment rate (percentage of economically active population)
	Percentage of people (aged 25 to 64) without higher education	-	Percentage of people (aged 25 to 64) without higher education

Notes: 'Higher education' refers to the International Standard Classification of Education (ISCED) levels 5-8.

(a) For analysis against air pollution data, the indicators for NUTS 2 and NUTS 3 regions were averaged for the years 2013 and 2014, whereas for Urban Audit cities they were averaged for the years 2011 and 2012 (see also Section 3.2.1). For analysis against climate indicators, 2014 was used for the indicators at NUTS 2 and NUTS 3 level, and 2011 was used for Urban Audit cities. For analysis against noise data, year 2011 was used for all spatial units. The ETC/ACM (2018) provides the details relating to the source, spatial coverage and processing of indicators.

(b) It is important to note that average GDP per capita does not provide any indication of the distribution of wealth between different population groups within a region, nor does it measure the average income ultimately available to private households within a region, as commuter flows may result in employees contributing to the GDP of one region (where they work) and to the household income of another region (where they live). In some countries, such as Luxembourg, a significant proportion of GDP refers to profits exported and not available for national consumption.

Source: Eurostat. Details available in ETC/ACM (2018a).

Understandably, these indicators do not offer a full picture of social vulnerability. There are other valid aspects that are not covered in the assessment because of either incomplete data coverage across Europe (e.g. proportion of people living in social housing) or the difficulty in measuring them (e.g. the quality of social support networks, which have been recognised as an important lifeline during extreme weather events) ([10]). In addition, the aspects of vulnerability are highly location and context specific, as the evidence review highlighted in Chapter 2. Furthermore, other personal characteristics, social and environmental factors also play a role; for example, the fact that older people are, in general, more susceptible to heat stress does not imply that every elderly person in Europe would be affected in the same manner. Nonetheless, the assessment in this chapter provides some indication of the large-scale patterns of unequal exposure and potential concentration of the impacts across Europe.

The associations between individual indicators of social vulnerability (Table 3.1) and exposure to individual environmental health hazards were analysed using correlation and by comparing the average exposure levels between NUTS and cities categorised according to vulnerability levels (see Box 3.2 for details).
No attempt was made to combine the individual indicators of vulnerability or hazards into an index (as was done in the European Spatial Planning Observation Network (ESPON) (2011), for example), because of the multitude of methods that could be used to combine the indicators and the lack of an established common practice for doing so (Carter and Mäkinen, 2011).

Box 3.2 Methods of analysing and presenting the association between levels of social vulnerability and exposure

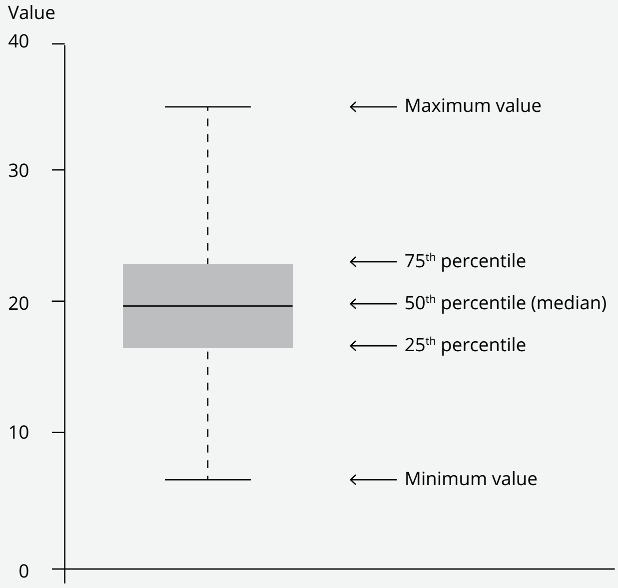
The following analysis methods were used (ETC/ACM, 2018a):

- Spearman's rank correlation, which first converts values to ranks and thereby decreases the influence of extreme values. The values of the correlation coefficient can range between -1 and 1, but in the case of this report they do not go below -0.5 and above 0.7. Positive numbers indicate that areas with higher social vulnerability tend to have higher exposure to an environmental health hazard; negative numbers indicate that areas with higher social vulnerability tend to have lower pollution exposure. Values close to zero indicate that there is little association between vulnerability and pollution or temperature exposure. The results of correlation analysis do not imply causation between the analysed phenomena but simply the coincidence of values. As a result of the analysis being carried out for the whole set of NUTS regions/Urban Audit cities (rather than a representative sample), no statistical significance was calculated.

- When describing the association between pollution exposure and a measure of vulnerability, the absolute difference and the ratio of mean pollution levels in the most vulnerable 20 % of spatial units (NUTS regions or Urban Audit cities) and the least vulnerable 20 % was calculated. While this method makes it possible to see the differences between the most and least vulnerable groups, it does not reflect the distribution of values across all vulnerability levels.

- To complement the analysis of ratios and differences, the mean air pollution and noise levels, and indicators of temperature extremes were presented for spatial units categorised in five equal-sized classes (quintiles) according to an aspect of vulnerability (e.g. levels of unemployment) using box-and-whisker plots.

Box-and-whisker plot



([10]) See also ETC/CCA (2018) for a discussion on factors driving social vulnerability to climate change.

3.2 Air pollution

3.2.1 Pollutants addressed

The air pollutants analysed in the study were the annual means of NO_2, PM_{10} and $PM_{2.5}$ and the indicator SOMO35 ([11]) for O_3 (Table 3.2). These pollutants have received the greatest attention from WHO Europe (2013d) and their effects are particularly serious in cities, where most Europeans live. The pollution data are based on interpolated 1 km by 1 km concentration grids. These data are combined with population data to calculate population-weighted average concentrations for each NUTS region or city. This gives a concentration value representing typical exposure for a person living in that area. However, because of the scale of analysis, the value does not reflect the (possibly large) differences in concentrations within cities and regions. As ambient concentrations of air pollutants vary according to meteorology as well as long-term emission trends, the pollutant concentrations were combined to calculate averages across 2 or 3 years to smooth out the meteorological variation. At the NUTS 2 and NUTS 3 scales, this was done for 2013 and 2014 for all pollutants. For Urban Audit cities, average concentrations were taken during the period 2010-2012 for PM_{10}, $PM_{2.5}$ and O_3 and during the period 2011-2012 for NO_2 ([12]). Nonetheless, the data are still affected by the meteorological and emission variations in the years considered. In addition, data have been sourced from measurements complemented with modelling results, which do not always accurately replicate the fine spatial variation in concentrations, especially for reactive pollutants such as NO_2. Finally, population-weighted concentrations have been used as a proxy for personal exposure when, in fact, this tends to be far more complex and variable. Details on methodology and limitations of the data are available in ETC/ACM (2018a).

The pollutants have different spatial concentrations across Europe. PM and O_3 follow large-scale patterns; the highest values of PM are present in Poland, the Balkans and northern Italy, with lower values across the rest of Europe. In the case of O_3, the highest values are found in southern Europe. In contrast, NO_2 concentrations do not follow large-scale patterns but occur in more densely populated regions (Map 3.1).

Table 3.2 Air pollutants considered in the report

Pollutant	Annual exposure ([a]) range (in NUTS 3)	EU air quality standards ([b])	WHO air quality guidelines ([c])	Measurement unit
NO_2	1-43	40	40	µg/m^3
PM_{10}	8-48	40	20	µg/m^3
$PM_{2.5}$	4-34	25	10	µg/m^3
O_3 SOMO35	693-8 786	- ([d])	- ([d])	µg/m^3·days

Notes: ([a]) Expressed as population-weighted concentration.

([b]) As per the EU Ambient Air Quality Directive (EU, 2008), per calendar year.

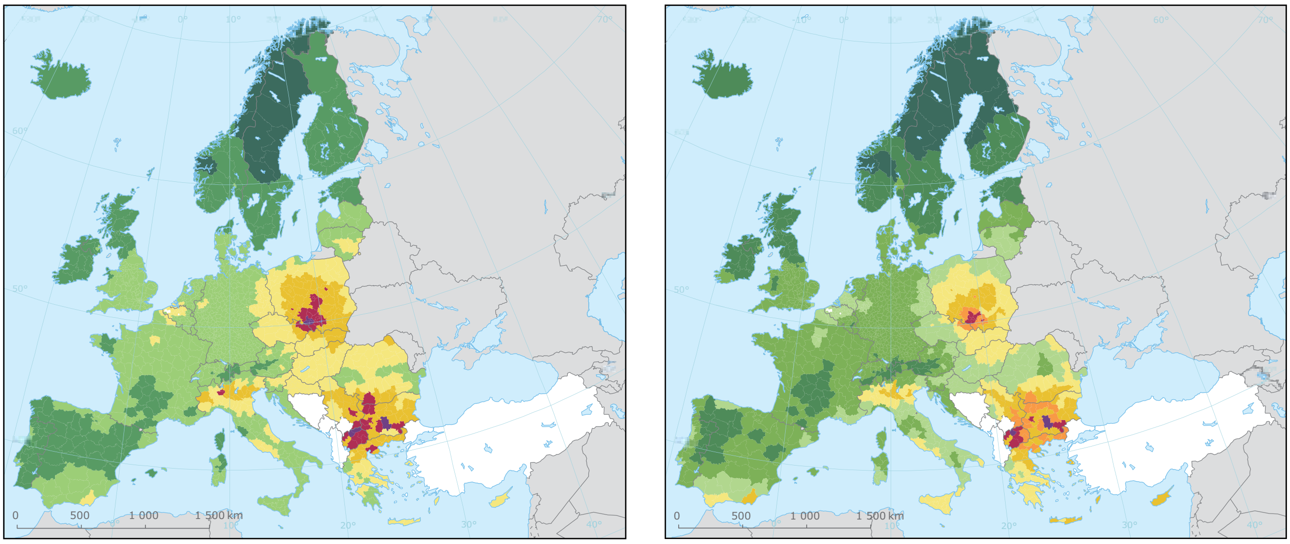
([c]) After WHO (2006), per calendar year.

([d]) No legal or recommended standards for SOMO35 are provided.

([11]) The sum of means over 35 parts per billion (ppb) (daily maximum 8-hour) is the yearly sum of the daily maximum of 8-hour running average over 35 ppb (70 µg/m^3) (WHO Europe, 2008).

([12]) The choice of years was driven by the availability of socio-economic data (see also Section 3.1.2).

Map 3.1 **Spatial distribution of exposure to four air pollutants across Europe (2013-2014)**



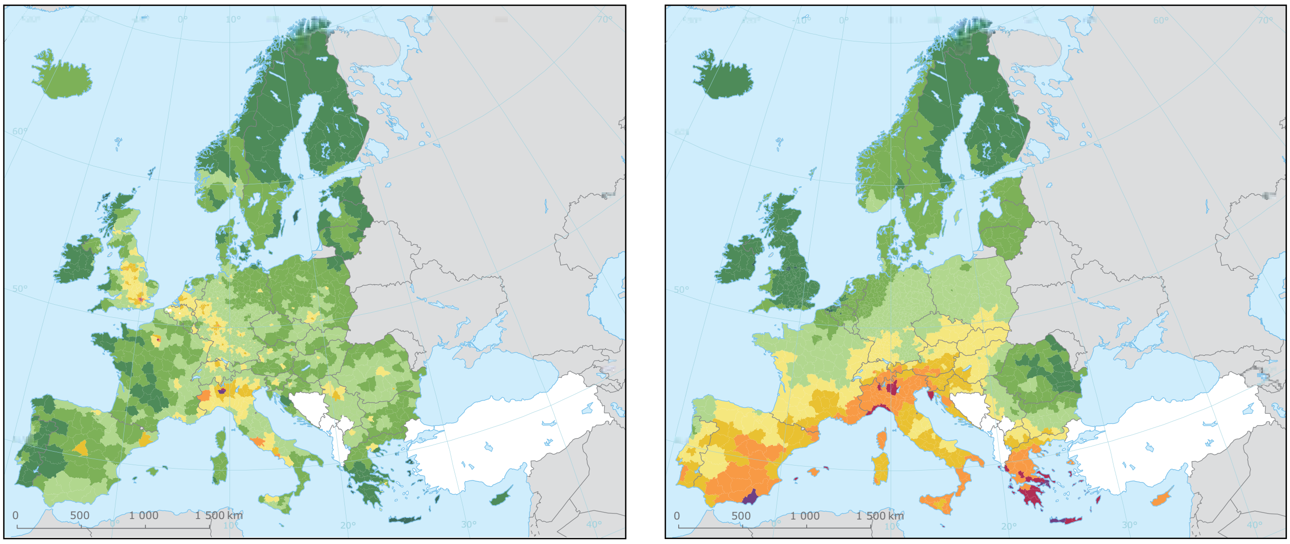
Spatial distribution of exposure to four air pollutants across Europe (2013-2014)

$PM_{2.5}$ annual mean in 2013-2014 (μg/m³)

< 5 | 5-10 | 10-15 | 15-20 | 20-25 | 25-30 | ≥ 30 | No data | Outside coverage

PM_{10} annual mean in 2013-2014 (μg/m³)

< 10 | 10-15 | 15-20 | 20-25 | 25-30 | 30-35 | 35-35 | 40-45 | ≥ 45



Spatial distribution of exposure to four air pollutants across Europe (2013-2014)

NO_2 annual mean in 2013-2014 (μg/m³)

< 5 | 5-10 | 10-15 | 15-20 | 20-25 | 25-30 | 30-35 | 35-40 | ≥ 40 | No data | Outside coverage

Ozone indicator SOMO35 annual mean in 2013-2014 (μg/m³·days)

< 1 000 | 1 000-2 000 | 2 000- 3 000 | 3 000-4 000 | 4 000-5 000 | 5 000-6 000 | 6 000-7 000 | 7 000-8 000 | ≥ 8 000

Note: Exposure is expressed as population-weighted concentrations; mapped for NUTS 3 regions.

Source: Based on ETC/ACM (2018a).

3.2.2 Analysing distribution of air pollution by regional vulnerability levels

The association between exposure to air pollution and levels of social vulnerability in Europe varied substantially depending on the pollutant, the vulnerability factor and the spatial unit of assessment considered (Table 3.3). Generally, areas characterised by lower socio-economic status (e.g. higher unemployment rate, lower proportion of population with higher education, lower average household income) tended to have higher levels of $PM_{2.5}$, PM_{10} and O_3 pollution. This is consistent with the previous cross-European study, which found that PM_{10} levels were around 30 % higher and the long-term O_3 concentrations were 30 to 40 % higher in the most disadvantaged regions compared with the wealthiest regions (CRESH, 2013). However, with regard to NO_2, the opposite was found — areas with higher economic status generally experienced higher levels of NO_2 pollution.

Table 3.3 Associations between exposure to air pollutants and indicators of social vulnerability across Europe

Spatial scale	Socio-demographic indicator	NO_2	$PM_{2.5}$	PM_{10}	O_3
NUTS 3 (2013-2014)	GDP per capita				
NUTS 2 (2013-2014)	Proportion of people with no higher education				
	Household income				
	Long-term unemployment rate				
	Proportion of elderly people				
	Proportion of young children				
Urban Audit cities (2011-2012) (a)	Proportion of people with no higher education				
	Unemployment rate				
	Proportion of elderly people				
	Proportion of young children				

Correlation coefficient

-0.6 -0.4 -0.2 0.2 0.4 0.6

Note: The shading represents the values of the Spearman's correlation coefficient, which measures association between aspects of social vulnerability and exposure to extreme temperatures (see Box 3.2). Positive values (in red) indicate that higher vulnerability tends to correspond to higher exposure levels; negative values (in blue) indicate that higher vulnerability tends to correspond to lower exposure levels. The intensity of the colour explains the strengths of the association.

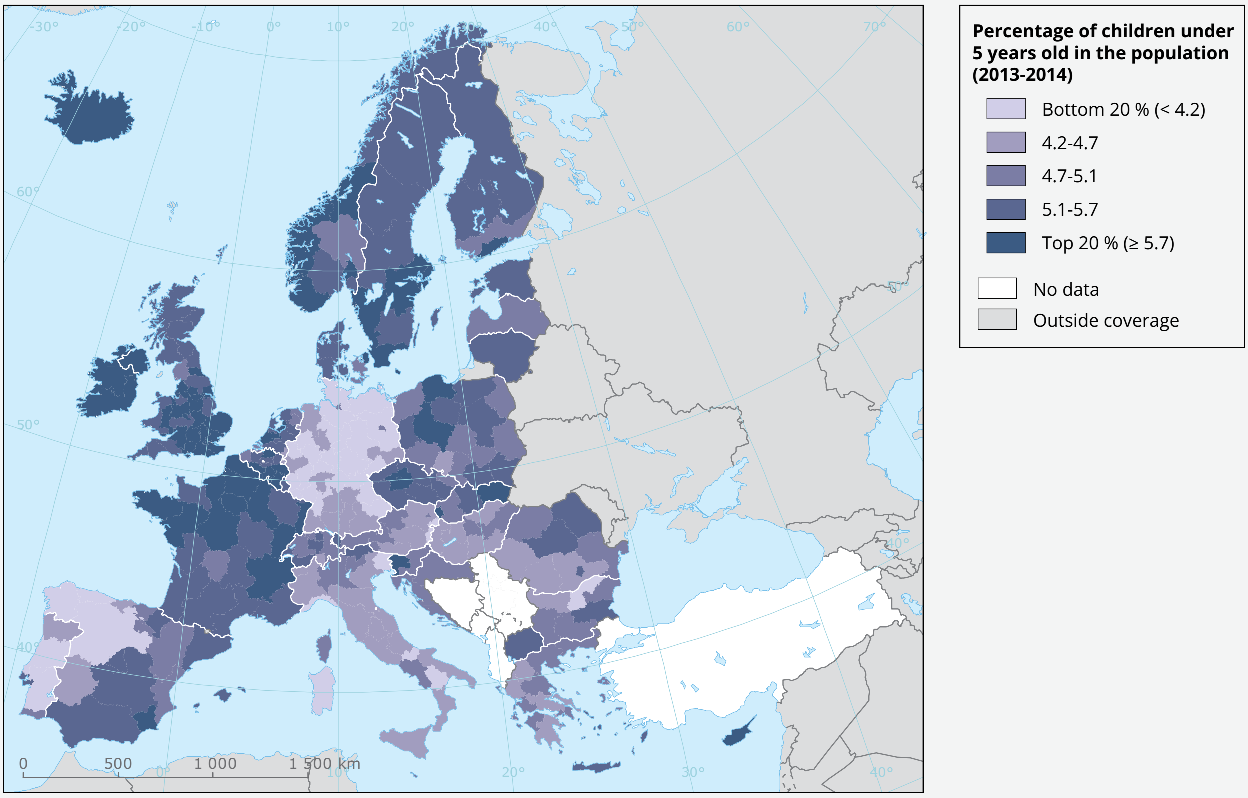
([a]) With the exception of associations between social vulnerability indicators and NO_2, where average concentrations were taken during the period 2011-2012.

Source: Based on ETC/ACM (2018a).

Box 3.3 Exposure of children to air pollution and extreme temperatures in Europe

The results of the assessment in this chapter show that the European regions and cities with higher proportions of young children tend to be less exposed to air pollution (with the exception of NO_2, see Table 3.3) and high temperatures (see Table 3.4). This association is mainly driven by the fact that the higher percentages of children under 5 years old are mostly found in northern Europe (Iceland, Ireland, Scandinavia, the United Kingdom,) and large parts of France (see map). These areas have relatively low levels of PM and O_3 pollution (see Map 3.1) and are less exposed to high temperatures (see Map 3.6).

These results should not be interpreted as a lack of children's exposure to air pollution and heat in Europe. The scientific evidence in Chapter 2 reports studies on the exposure of children to air pollution and the impacts it has on their health for countries such as Germany (Gottschalk, C., et al., 2011), Sweden (Oudin et al., 2016; Chaix et al., 2006) and the United Kingdom (Aether, 2017a). Therefore, the risks to children's health are still present, even though the regions with higher percentages of children have lower levels of pollution and lower heat hazard overall.



Source: Eurostat.

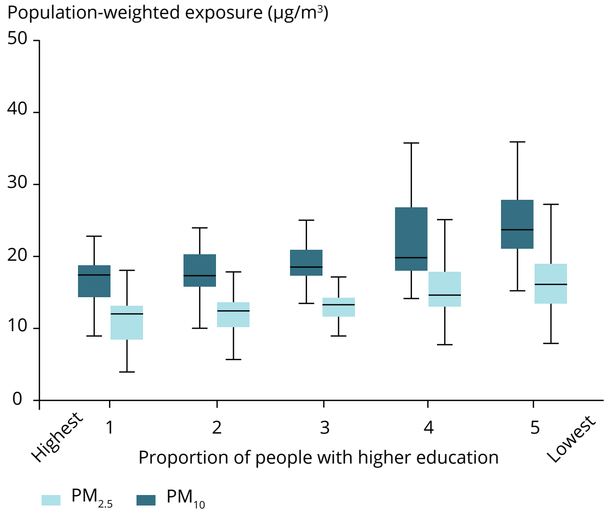
3.2.3 Regional exposure to particulate matter

Generally, regions characterised by lower socio-economic status tended to have higher $PM_{2.5}$ and PM_{10} exposure than regions with higher socio-economic status (Table 3.3). The most vulnerable 20 % of the NUTS 2 regions (in relation to unemployment, household income and level of education) was exposed to $PM_{2.5}$ and PM_{10} pollution levels that, on average, were 1.3-1.5 times higher than the levels experienced by the least vulnerable 20 % of regions. This means that the absolute difference in pollution between the most and the least vulnerable regions was around 3-5 µg/m³ for $PM_{2.5}$ and 8-9 µg/m³ for PM_{10} (see Figure 3.1 for the percentage of people without higher education). In contrast, $PM_{2.5}$ exposure tended to be lower in NUTS 2 regions with a higher proportion of children (Box 3.3).

Most of the NUTS 2 regions in both the top 20 % of PM_{10} exposure and in the top 20 % of long-term unemployment rate are found in Bulgaria, Greece, parts of Italy and Spain and Slovakia (Map 3.2). Extensive areas of south-eastern Europe and Italy are in both the top 20 % of regions with high exposure to $PM_{2.5}$ and the most deprived 20 % of regions regarding higher education qualifications ([13]).

NUTS 3 regions with the lowest GDP per capita experience, on average, higher exposure to PM_{10} concentrations than the remaining NUTS 3 regions; the population-weighted concentrations of PM_{10} in Europe were around 26 µg/m³ in the bottom 20 % of NUTS 3 regions in terms of GDP, compared with 19 µg/m³ in the remaining NUTS 3 regions. For $PM_{2.5}$, the population-weighted concentrations were 18 µg/m³ in the most deprived 20 % of NUTS 3 regions, versus 13 µg/m³ in the remaining NUTS 3 regions (Figure 3.2). NUTS 3 regions that were among both the highest 20 % for $PM_{2.5}$ exposure and the most deprived 20 % with regard to GDP per capita during the period 2013-2014 were located mainly in central and eastern Europe (Map 3.3).

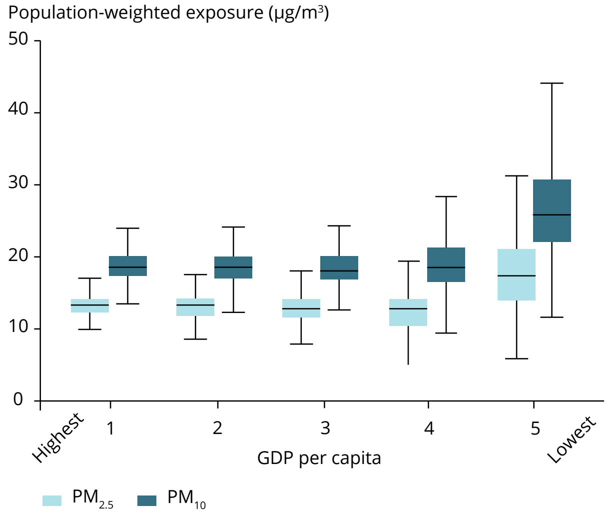
Figure 3.1 Differences in exposure to $PM_{2.5}$ and PM_{10} (µg/m³) among NUTS 2 regions in Europe, classified according to the proportion of people without higher education in the population (2013-2014)



Note: The classification of regions is based on quintiles, i.e. 1 represents the bottom 20 % and 5 represents the top 20 % of regions in relation to the proportion of people without higher education in the population. 1 corresponds to the lowest social vulnerability (the highest percentage of people with higher education in the population) and 5 corresponds to the highest social vulnerability (the lowest percentage of people with higher education in the population).

Source: Based on ETC/ACM (2018a).

Figure 3.2 Differences in exposure to PM_{10} and $PM_{2.5}$ among NUTS 3 regions in Europe, classified according to GDP per capita (2013-2014)

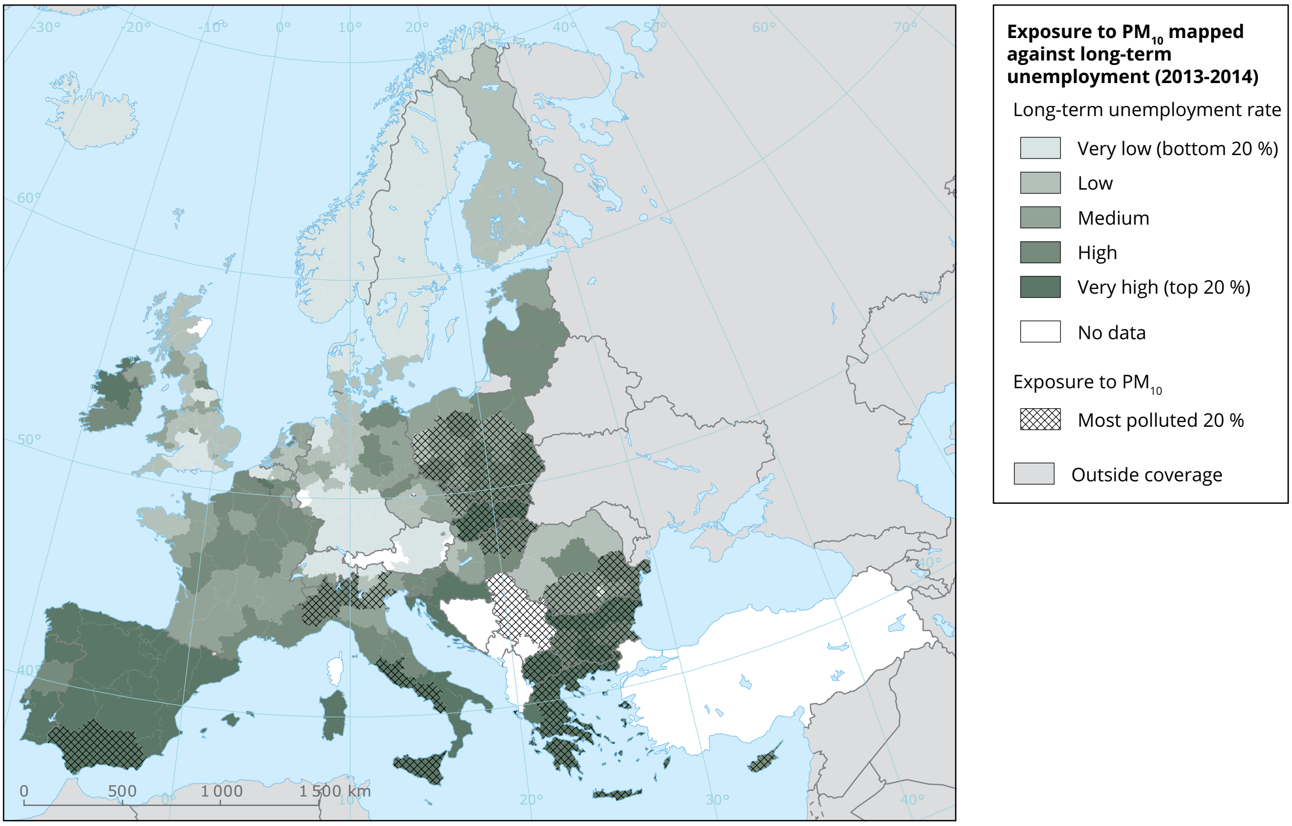


Note: The classification of regions is based on quintiles, i.e. 1 represents the top 20 % and 5 represents the bottom 20 % of regions in relation to GDP per capita. Therefore, 1 corresponds to the lowest vulnerability (the highest GDP per capita) and 5 corresponds to the highest vulnerability (the lowest GDP per capita).

Source: Based on ETC/ACM (2018a).

([13]) See Figure 4.3 in ETC/ACM (2018a).

Map 3.2 Exposure to PM_{10} mapped against long-term unemployment (2013-2014)



Note: Exposure is expressed as population-weighted concentrations; mapped for NUTS 2 regions.

Source: Based on ETC/ACM (2018a).

The most vulnerable cities, in relation to levels of unemployment and percentage of citizens without higher education, tended to have average levels of PM_{10} pollution that were 1.2 times higher than the average levels in the least vulnerable cities, presenting a difference of around 4 µg/m³.None of the 56 cities in Europe with average annual PM_{10} levels exceeding 40 µg/m³ appear in the lowest unemployment class. Among the cities with the highest levels of unemployment and highest PM_{10} exposure are Stara Zagora (Bulgaria), Turin (Italy) and Nicosia (Cyprus) ([14]).

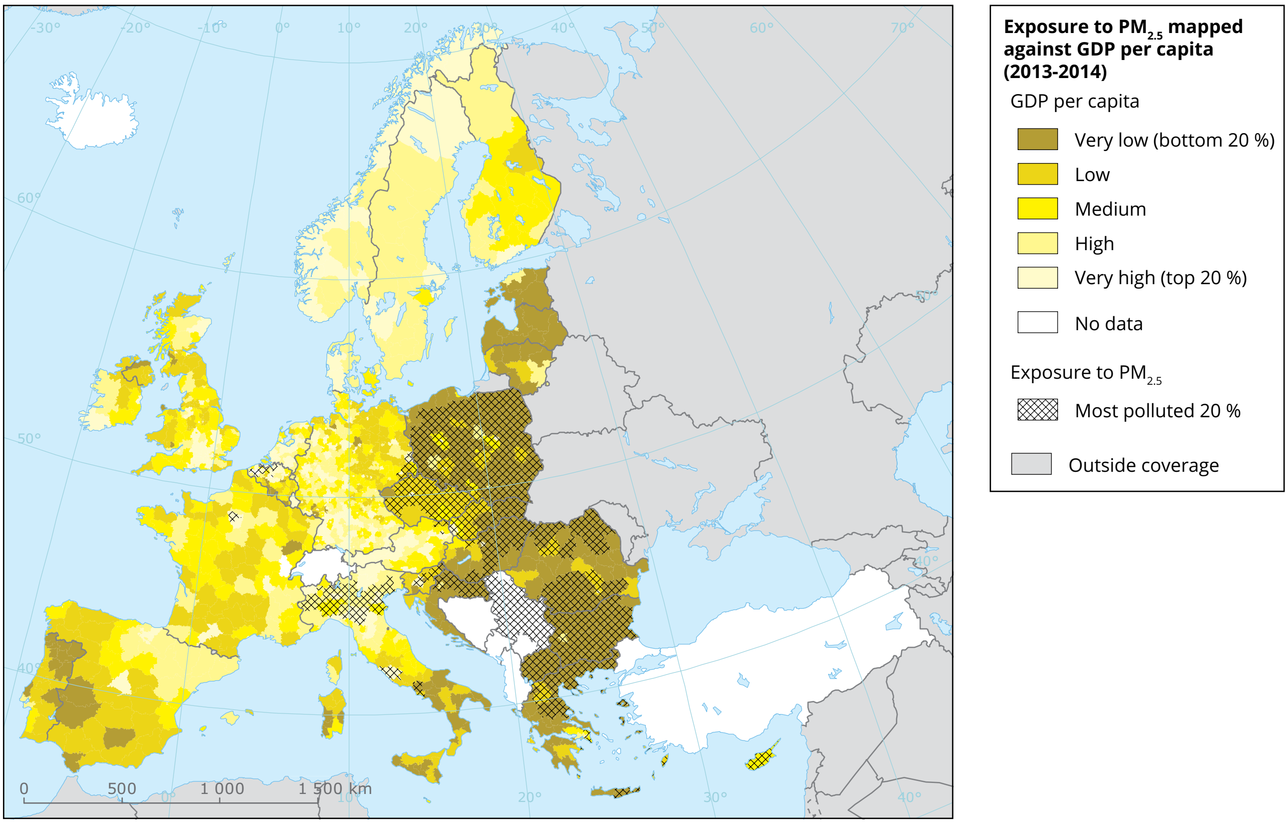
3.2.4 Regional exposure to ozone

In contrast to PM, the economic aspects of social vulnerability (GDP per capita at NUTS 3 level and household income deprivation at NUTS 2 level) are only weakly associated with O_3 exposure. Still, the poorest 20 % of NUTS 3 regions were exposed, on average, to levels of O_3 SOMO35 that were 1.3 times higher than those experienced by the wealthiest 20 %. The NUTS 3 regions that were among both the highest 20 % for O_3 exposure and the lowest 20 % for GDP per capita were primarily located in Croatia, Greece, Italy and Spain.

The strongest associations with exposure to O_3 are found for higher education deprivation (at NUTS 2 level), unemployment and demographic factors (at both NUTS 2 and city scale). NUTS 2 regions with a higher proportion of people without tertiary education also tended to have higher exposure to O_3; the most vulnerable 20 % of these regions in this regard was exposed, on average, to twice as much O_3 SOMO35 as the least deprived 20 %. This can be explained by the geographic variation in O_3 SOMO35, with much higher concentrations present in the south of Europe (see Map 3.1). As a consequence, the NUTS 2 regions, which are in both the top 20 % for ozone exposure and the bottom 20 % for higher education qualifications, are all found in southern Europe, in Greece, Italy and Portugal.

([14]) The data on unemployment are missing for a high proportion of Urban Audit cities, so only limited conclusions can be drawn.

Map 3.3 Spatial distribution of exposure to $PM_{2.5}$ and GDP per capita across NUTS 3 regions (2013-2014)



Note: Exposure is expressed as population-weighted concentrations; mapped for NUTS 3 regions.

Source: Based on ETC/ACM (2018a).

Twenty per cent of NUTS 2 regions with the highest long-term unemployment rate were exposed to about 1.7 times more O_3 SOMO35 than the 20 % with the lowest long-term unemployment rate, at 5 392 and 3 097 µg/m³·days respectively. This was also the case for higher education deprivation. The regions in both the top 20 % for O_3 exposure and the top 20 % for long-term unemployment were found in parts of southern Europe (Map 3.4).

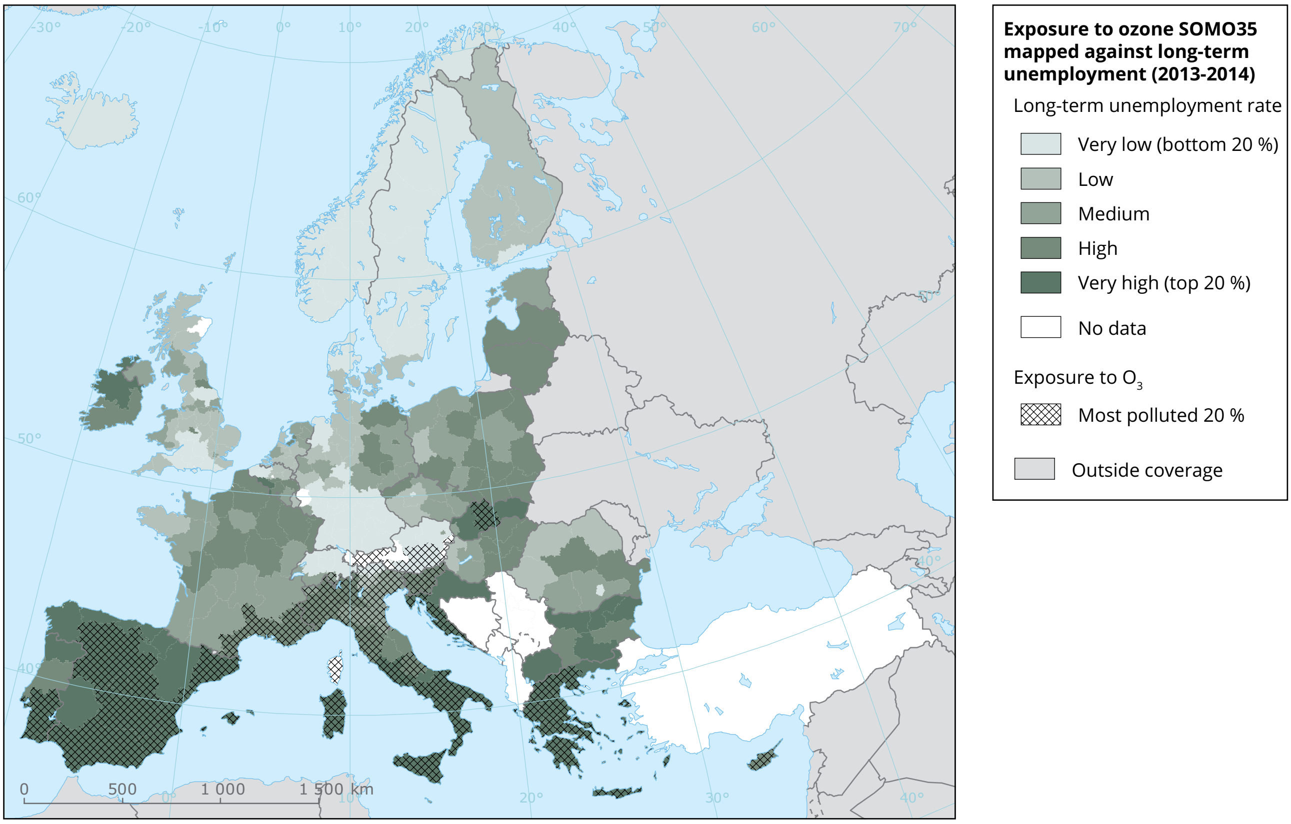
The associations between O_3 exposure, and unemployment and age-related vulnerability are relatively consistent between NUTS 2 and Urban Audit city scales (Table 3.3). However, the link between higher education deprivation and O_3 exposure is much stronger at NUTS 2 level than at Urban Audit city level. One plausible explanation for this may be an urban-rural gradient in access to higher education in parts of Europe characterised by the highest O_3 exposure and lowest average higher education. This would mean that the Urban Audit cities in these regions have a greater proportion of people with higher education than the NUTS 2 regions to which they belong, weakening the association between higher education deprivation and O_3 exposure.

NUTS 2 regions and cities with a greater proportion of elderly people have been identified as having higher exposure to ground-level O_3, while regions with the largest proportion of young children have the lowest level of exposure (Figure 3.3; see also Box 3.3).

3.2.5 Regional exposure to nitrogen dioxide

In contrast to PM and O_3, exposure to NO_2 tended to be higher in regions categorised as less vulnerable because of economic factors, at both NUTS 2 and NUTS 3 scales. The top 20 % of NUTS 3 regions in terms of GDP per capita were exposed to NO_2 concentrations around 8 µg/m³ higher (or around 1.6 times the concentration) than those experienced by the poorest 20 % of NUTS 3 regions. Similarly, at NUTS 2 level, average pollution for regions in the top 20 % of average household income was 1.5 times, or 7 µg/m³, higher than in the NUTS 2 regions with the lowest household

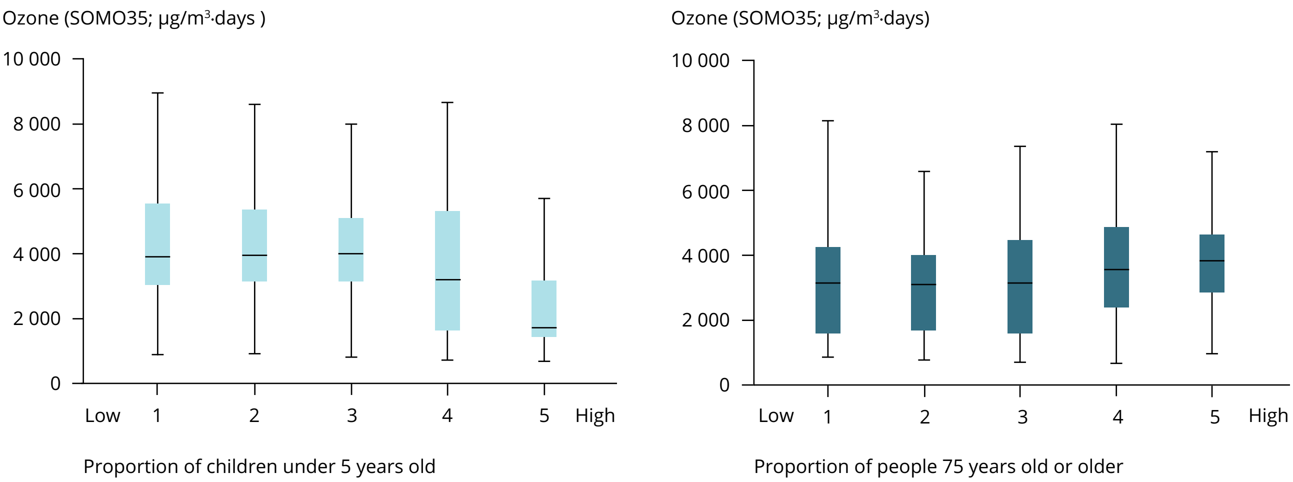
Map 3.4 Exposure to O_3 SOMO35 mapped against long-term unemployment (2013-2014)



Note: Exposure is expressed as population-weighted concentrations; mapped for NUTS 2 regions.

Source: Based on ETC/ACM (2018a).

Figure 3.3 Differences in exposure to O_3 SOMO35 among Urban Audit cities classified according to the proportion of children under 5 years old (left) and the proportion of people 75 years old or older (right) in the population (2011)



Note: The classification of cities is based on quintiles, i.e. 1 represents the bottom 20 % and 5 represents the top 20 % of cities in relation to percentage of the elderly or children in the population. 1 corresponds to the lowest proportion of vulnerable people (the elderly or young children), and 5 corresponds to the highest proportion of vulnerable people (the elderly or young children).

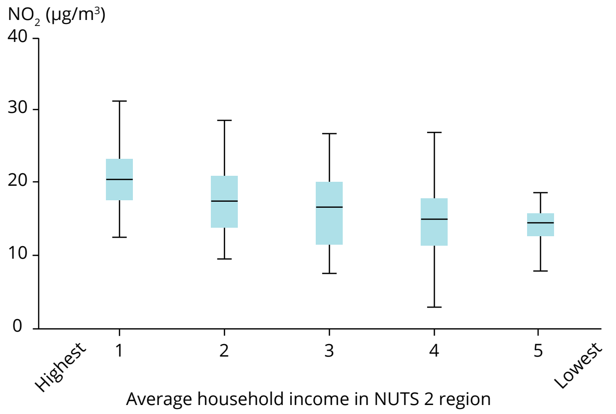
Source: Based on ETC/ACM (2018a).

income (Figure 3.4). In addition, cities with lower levels of unemployment tend to have higher concentrations of NO_2 (Table 3.3).

At the spatial scale of assessment, regions with higher levels of urbanisation and/or industrialisation tend to also have higher volumes of traffic, generating NO_2 pollution. Therefore, the most polluted NUTS 2 regions are usually located in densely populated regions of Europe, such as northern Italy, western Germany and the United Kingdom (Map 3.5).

The finer scale associations between social vulnerability and NO_2 concentrations, identified in local studies in Section 2.2.3, are not picked up on this scale of assessment (Box 3.4). This emphasises again that the results of this assessment are simply indicating the presence of inequalities associated with environmental health hazards in Europe, and that their particular character and intensity in local settings need to be established through more detailed studies.

Figure 3.4 Differences in the exposure to NO_2 among NUTS 2 regions classified according to average household income (2013-2014)



Note: The classification of regions is based on quintiles, i.e. 1 represents the top 20 % and 5 represents the bottom 20 % of regions in relation to household income. 1 corresponds to the lowest vulnerability (highest average household income), and 5 corresponds to the highest vulnerability (lowest average household income).

Source: Based on (ETC/ACM, 2018a).

3.3 Noise

3.3.1 Noise indicators used in the report

In line with the noise thresholds in the Environmental Noise Directive (END; 2002/49/EC) (EU, 2002), the noise indicators used in this study were the proportion of people exposed to road noise of L_{den} ([15]) ≥ 55 dB (an average of day, evening and night) and L_{night} ([16]) ≥ 50 dB (night noise levels) in a given spatial unit. Only exposure to road noise was considered in this study, as this is the dominant source of noise exposure in most cities and exposure figures from all transport sources (as required by the END) were available for very few cities (ETC/ACM, 2018a).

These long-term average noise exposure indicators are common predictors of adverse health effects in the population (Jarosińska et al., 2018). Two different data sets were used to compile these data for NUTS regions and Urban Audit cities: (1) a single estimate of the number of people exposed to noise from roads for each urban area containing at least 100 000 people as reported by the Member States under the END; and (2) an interpolated road noise map covering areas outside agglomerations at 1 km by 1 km resolution.

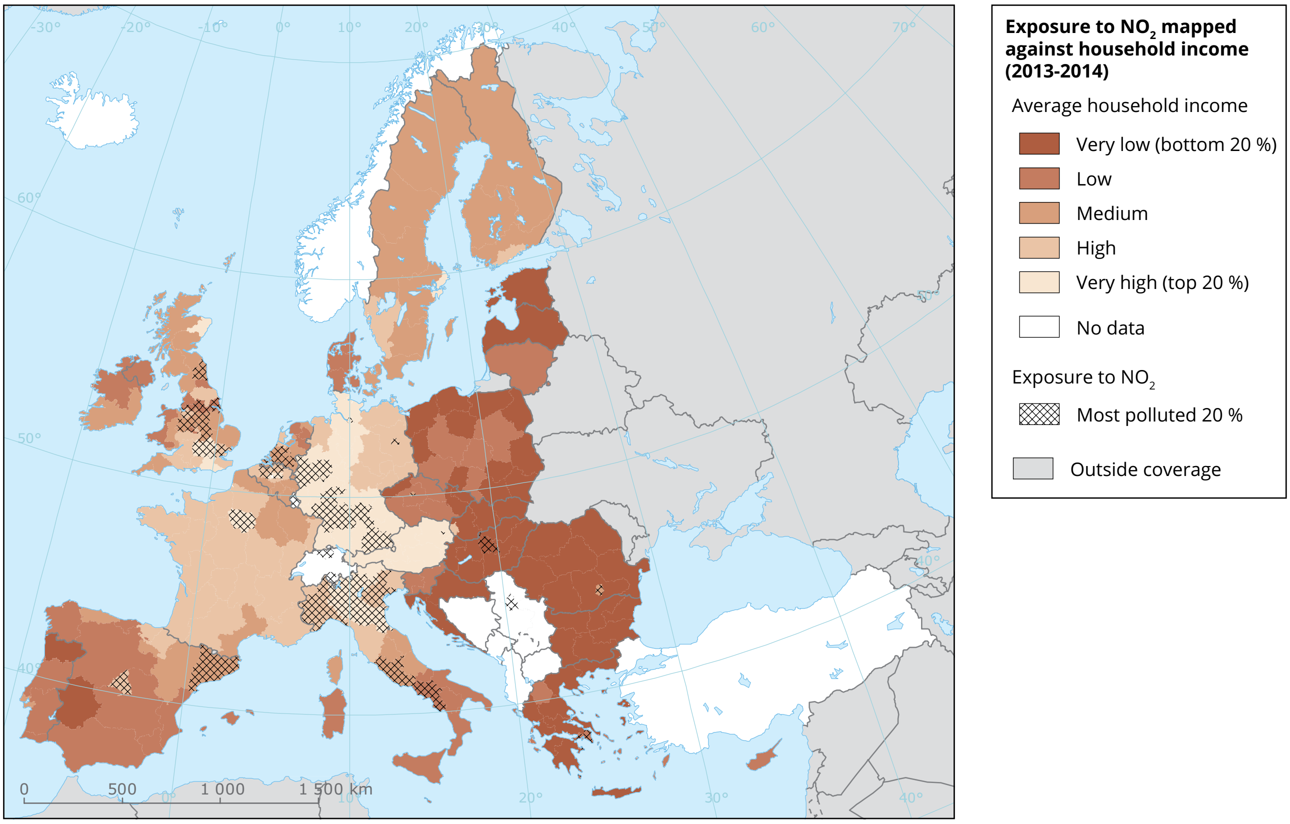
The second data set has greater uncertainty, as it extends the coverage to areas for which no data have been reported by Member States. This assessment uses only the road noise data reported under the END in 2012, which relates to the situation in 2011 (ETC/ACM, 2018a).

In contrast to air pollution, the spatial distribution of exposure to road noise does not show any large-scale patterns across Europe. Perhaps counter-intuitively, there did not appear to be a systematic difference between urban and rural areas. This may be partly because of differences in the input data and the calculation methods used in different countries, especially concerning the types of roads included (in some countries, only major roads were considered in the mapping, whereas in other countries, minor roads, or even all roads, were included). In addition, noise exposure in more rural areas could be high if dwellings are concentrated around major roads with heavy traffic, which tends to happen in the surrounding areas of major cities (ETC/ACM, 2018a).

([15]) Day-evening-night equivalent level of noise, measured over a 24-hour period, with a 10 dB penalty added to the levels between the hours of 23.00 and 07.00 and a 5 dB penalty added to the levels between the hours of 19.00 and 23.00, to reflect people's extra sensitivity to noise during the night and in the evening. It is designed to assess annoyance (EEA, 2014b). The END (2002/49/EC) provides a technical definition for this indicator in Annex 1 (EU, 2002).

([16]) Night equivalent level of noise, measured overnight between the hours of 23.00 and 07.00, also known as the night noise indicator, is designed to assess sleep disturbance (EEA, 2014b). The END (2002/49/EC) provides a technical definition for this indicator in Annex 1 (EU, 2002).

Map 3.5 Exposure to NO_2 mapped against household income (2013-2014)



Note: Exposure is expressed as population-weighted concentrations; mapped for NUTS 2 regions.

Source: Based on ETC/ACM (2018a).

As a result of the low spatial resolution of socio-demographic indicators (see Section 3.1.2), the full precision of current noise maps could not be used in analysing the associations between exposure to noise and social vulnerability; instead, a single indicator had to be derived for each urban area or region. It has been assumed that exposure is uniformly distributed within agglomerations. In reality, exposure to noise is much more localised than exposure to air pollution and ambient levels vary considerably across short distances. A major limitation of using a single noise exposure indicator at the regional or city scale is the difficulty in detecting the noise exposure variability within neighbourhoods. Furthermore, the noise data were only available for around 35 % of the Urban Audit cities, resulting in incomplete and possibly unrepresentative data coverage. Given these uncertainties, the results presented below should be interpreted with caution (ETC/ACM, 2018a).

3.3.2 Analysing distribution of noise by regional vulnerability levels

In general, the associations between noise exposure and social vulnerability were less clear than in the case of air pollution. There is a relatively even distribution of noise levels across European regions; most of the NUTS 3 regions are very similar in terms of the percentage of people exposed to Lden ≥ 55 dB: in 60 % of the NUTS regions, noise exposure ranges between 31 % and 35 %.

Box 3.4 Effects of scale on the results of analyses

There is no right or wrong scale of analysis. The geographic extent and spatial granularity of analysis is probably the most important factor affecting both its ability to detect associations between pollution exposure and social indicators, and the interpretation of patterns detected. This factor is highlighted as a key methodological issue in observational studies of pollution and socio-economic status (EC, 2016b) as well as in environmental justice studies more broadly (Gegisian et al., 2006).

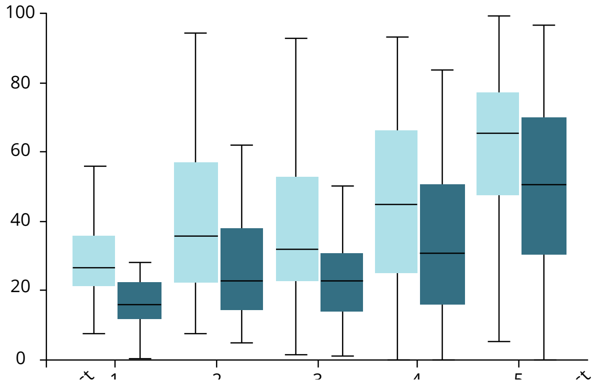
Performing a Europe-wide assessment implies a compromise between the geographic extent and the level of detail. Within individual NUTS regions, or cities, there is likely to be a great deal of heterogeneity in both exposure to environmental health hazards and social characteristics. The problems associated with scale choice are referred to as the modifiable areal unit problem (Openshaw, 1983). Generally, aggregated socio-demographic or environmental data are less reliable as indicators when they are unable to display the internal diversity of the spatial unit. The ecological fallacy is another problem, as aggregate data (such as unemployment rate) are ascribed to all individuals in an area (Cutter et al., 1996). The issue of aggregation of data affects studies on all scales and sometimes results in differences in correlation coefficients. For example, a study looking at the exposure of children to NO_2 in Malmö, Sweden, found different associations between exposure and socio-economic status, depending on whether a scale of individual building or a neighbourhood was considered (Chaix et al., 2006).

In the case of PM, the associations between more vulnerable populations and air pollution are similar at different spatial scales, although the processes grouping poorer people and worse environmental quality are likely to be different. In the case of NO_2, and as a result of data aggregation, the analyses of associations between social vulnerability and exposure at the scale of NUTS regions and Urban Audit cities have produced different results compared with the local-scale studies discussed in Section 2.2.3. The coarser scale analysis does not detect the within-unit variability. Consequently, while the wealthier (i.e. frequently more urbanised or more industrialised) regions and cities have higher average levels of NO_2, poorer people within some of these areas may still live in more polluted locations, as became apparent from the literature review.

While the knowledge of local-level associations between social vulnerability and exposure at the fine scale is useful to local decision-makers, at broader scales the knowledge of places where the pollution is concentrated and who is affected can guide policies at a more strategic level (see also Section 6.2). This emphasises the point made in Section 3.1.1 that analysing unequal exposure of different groups to pollution is most usefully done across multiple spatial scales.

The only associations of note occur between noise levels and unemployment in Urban Audit cities, and household income deprivation at the NUTS 2 level, which suggests that cities and regions containing poorer populations have higher exposure to noise. This is a tentative finding, particularly because noise exposure data could be obtained for only around 35 % of cities in the Urban Audit. Among the top 20 % of these cities with regard to the highest unemployment rate, 61 % of people were exposed to average noise levels of 55 dB or more, compared with 35 % in the 20 % of cities with the lowest unemployment rate (a 1.7 times difference between the top and bottom 20 % of cities). The relative difference in exposure between cities with the highest and lowest levels of unemployment was even greater for night-time noise (2.1 times): 48 % and 23 % of the population, respectively (Figure 3.5). This finding is in agreement with other studies comparing smaller areas within individual cities, which found that noise exposure is higher in more deprived districts of cities (see Section 2.3.3). However, the mechanisms underlying the associations between socio-economic status and exposure to noise between neighbourhoods in cities (see Section 2.1) are likely to differ from those operating at between-city level to differentiate large spatial units across the whole of Europe. Moreover,

Figure 3.5 Differences in the proportion of the population exposed to high levels of noise among European cities classified according to unemployment levels (2011)



Note: The levels of unemployment represent quintiles (i.e. classes containing 20 % of the cities, ranked according to values), where 1 represents the lowest vulnerability and 5 the highest. The noise data and unemployment data were available simultaneously for 254 out of 918 Urban Audit cities, with varying coverage across countries. This chart covers cities in the following 18 countries: Belgium, Bulgaria, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Ireland, Italy, Lithuania, Latvia, the Netherlands, Portugal, Spain, Sweden and the United Kingdom.

Source: Based on (ETC/ACM, 2018a)

it should be noted that, across cities within each unemployment quintile, there is a great variability in the percentage of people exposed, meaning that there are cities with relatively high exposure across all ranges of deprivation. Detailed findings can be found in ETC/ACM (2018a).

3.4 Extreme temperatures

3.4.1 Indicators used in the report

The extreme temperature indicators in this report have been chosen according to their relevance to the impacts of extreme temperatures on human health, especially taking into account the indicators of social vulnerability, and they include the following indicators based on the E-OBS dataset (Haylock et al., 2008) ([17]):

- The number of days with a maximum temperature exceeding 30 °C and a minimum temperature above 20 °C per year (SD30TN20), averaged over the period 1987-2016. The combination of hot days and warm nights increases the risk of heat stress (Murage et al., 2017), therefore this indicator is particularly relevant for assessing the proportion of elderly people in the population who are prone to heat-related impacts.

- The number of hot summer days when the temperature exceeds 35 °C per year (SD35), averaged over the period 1987-2016. This may bear particular relevance to the health of workers in outdoor or high-temperature indoor settings, who tend to have a lower level of education (see also Section 2.1.2). It has also been estimated that as many as 40 % of deaths associated with heat occur on isolated hot days during periods that would not be classified as heatwaves (Baccini et al., 2011; Basagaña et al., 2011) and, consequently, individual hot days may have an impact on the health of sensitive groups, such as the elderly.

- The number of cooling degree days (CDDs) per year, averaged over the period 1990-2015. CDD is a measurement designed to quantify the demand for energy needed to cool a building in order to keep it at a comfortable temperature. In this report, it is defined as the sum of the difference in degrees between 21 °C and the mean temperature over the year, for the days when the mean daily temperature is higher than 21 °C.

- The number of heating degree days (HDDs) per year, averaged over the period 1990-2015. HDD is a measurement designed to quantify the demand for energy needed to heat a building in order to keep it at a comfortable temperature. In this report, it is defined as the sum of the difference (in °C) between 18 °C and the mean daily temperature over the year, for the days when mean daily temperature is lower than 15 °C ([18]). The number of CDDs and HDDs is useful in differentiating between areas based on the need for heating or cooling homes, and therefore HDDs and CDDs are both relevant to issues of energy affordability and energy poverty. Furthermore, 'non-extreme' temperatures outside a local comfort temperature range are also linked to increased mortality and other adverse health outcomes (Gasparrini et al., 2015). Consequently, identifying areas with the greatest deviation from comfort temperatures can help to approximate the places where human health is at risk ([19]).

Map 3.6 presents the spatial distribution of the above indicators across Europe ([20]). Unsurprisingly, the indicators relating to high temperatures have the highest values in southern and south-eastern Europe. Their spatial distribution varies slightly: areas with maximum temperatures exceeding 35 °C for over 10 days are concentrated in the Iberian Peninsula, while areas with the highest number of combined hot days

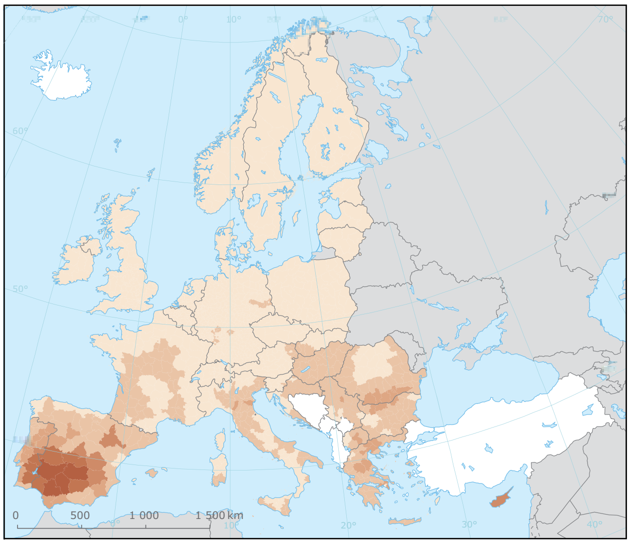
([17]) E-OBS dataset is from the EU-FP6 project ENSEMBLES (http://ensembles-eu.metoffice.com), data is provided by the European Climate Assessment and Dataset (ECA&D) project (http://www.ecad.eu; accessed 29 November 2018).

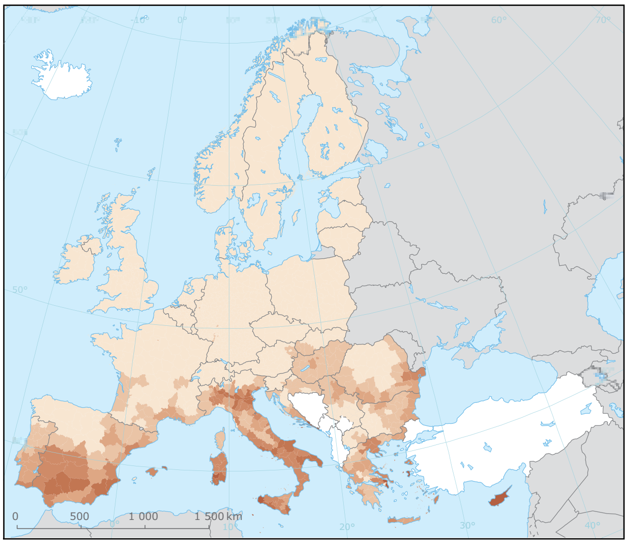
([18]) There are various temperature baselines used in calculating HDDs and CDDs: see Spinoni et al. (2018), for example. The baselines for calculating HDDs in this report follow the Eurostat methodology: see https://www.eea.europa.eu/data-and-maps/indicators/heating-degree-days (accessed 29 November 2018). The calculation of HDDs and CDDs according to one threshold across Europe does not take into account the acclimatisation of people to higher or lower temperatures or the quality of the built environment.

([19]) The indicators used in this report are based on temperature only, whereas high humidity during hot days and warm nights can be an additional factor, amplifying the heat impacts on human health. However, in the European context (compared with other parts of the world), heatwaves tend to be dry rather than humid (Russo et al., 2017).

([20]) The data were recalculated from a 25 km by 25 km grid for the NUTS 2 and NUTS 3 regions using area-based averages. In the case of Urban Audit cities, the value of the extreme temperature indicator was extracted using the centroid of the city.

Map 3.6 Spatial distribution of extreme temperature indicators across Europe





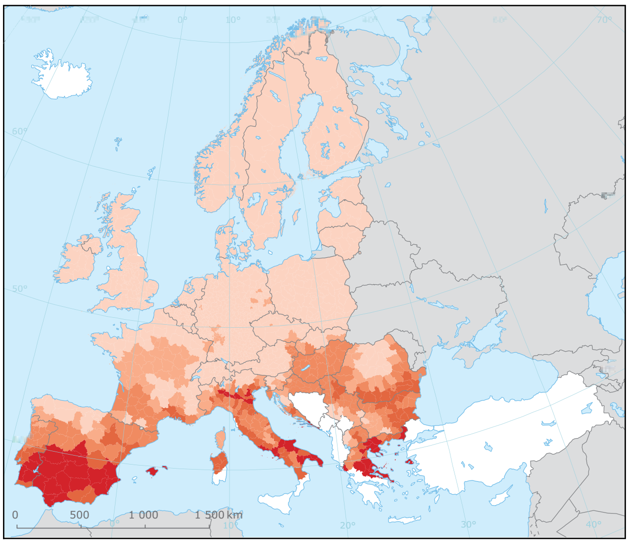
Spatial distribution of extreme temperature indicators across Europe

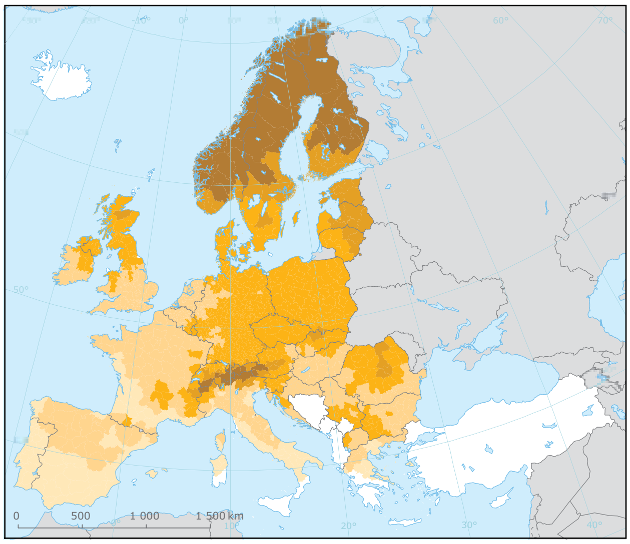
Number of hot summer days (T_{max} > 35 °C) per year (1987-2016 average)

< 0 | 1-5 | 6-10 | 11-20 | 21-30 | ≥ 31

Number of combined summer days (T_{max} > 30 °C) and tropical nights (T_{max} > 20 °C) per year (1987-2016 average)

< 0 | 1-5 | 6-10 | 11-20 | 21-30 | ≥ 31 | No data | Outside coverage





Spatial distribution of extreme temperature indicators across Europe

Cooling degree days per year (1990-2015 average)

< 50 | 51-100 | 101-200 | 201-300 | ≥ 301

Heating degree days per year (1990-2015 average)

< 2 000 | 2 001-3 000 | 3 001-4 000 | 4 001-5 000 | ≥ 5 001 | No data | Outside coverage

Note: Mapped for NUTS 3 regions.

Source: EEA based on the E-OBS dataset (updated from Haylock et al., 2008).

3.4.2 Analysing distribution of high and low temperatures by regional vulnerability levels

Generally, the NUTS regions classified as more vulnerable as a result of low GDP or a high proportion of people of low socio-economic status correspond to areas affected by high temperature (Table 3.4). This is because many regions in southern and south-eastern Europe have high levels of unemployment, lower incomes and lower levels of educational attainment than the European average.

The top 20 % of NUTS 2 regions in terms of long-term unemployment experience, on average, 10 times the number of CDDs when compared with the 20 % of NUTS 2 regions with the lowest long-term unemployment (199 and 19 CDDs, respectively). The areas most affected by both long-term unemployment and high temperatures are located in parts of Bulgaria, Croatia, Greece, Italy and Spain (Map 3.7). This is in agreement with the EU-SILC data on the ability of people to keep their houses at comfortable temperatures during winter and summer (see Map 2.4).

The areas in the bottom 20 % of NUTS 2 regions regarding the percentage of people with higher education experience, on average, 1.7 times as many days with a maximum temperature over 35 °C as the regions in the top 20 %. This may mean that the areas where lower levels of education and high temperatures overlap experience more pronounced negative impacts of high temperatures when it comes to the health of people working outside or in already hot environments. Lower levels of education and substantial average number of hot days overlap spatially in southern Portugal and parts of Bulgaria and, to a lesser extent, in parts of Greece, Hungary, Italy and Romania (Map 3.8).

The associations between the socio-economic status aspects of vulnerability and extreme temperatures are much less pronounced for cities than for the NUTS regions. This is similar to the findings for air pollution and it could be linked to the way in which cities usually differ from the regions they are located in, especially in relation to income or levels of education (EC, 2017c).

Table 3.4 Associations between exposure to extreme temperatures and indicators of social vulnerability in Europe

Spatial scale	Socio-demographic indicator	SD35	SD30TN20	CDD	HDD
NUTS 3 (2013-2014)	GDP per capita				
NUTS 2 (2013-2014)	Proportion of people with no higher education				
	Household income				
	Long-term unemployment rate				
	Proportion of elderly people				
	Proportion of young children				
Urban Audit cities (2011-2012) ([a])	Proportion of people with no higher education				
	Unemployment rate				
	Proportion of elderly people				
	Proportion of young children				

Correlation coefficient

-0.6 -0.4 -0.2 0.2 0.4 0.6

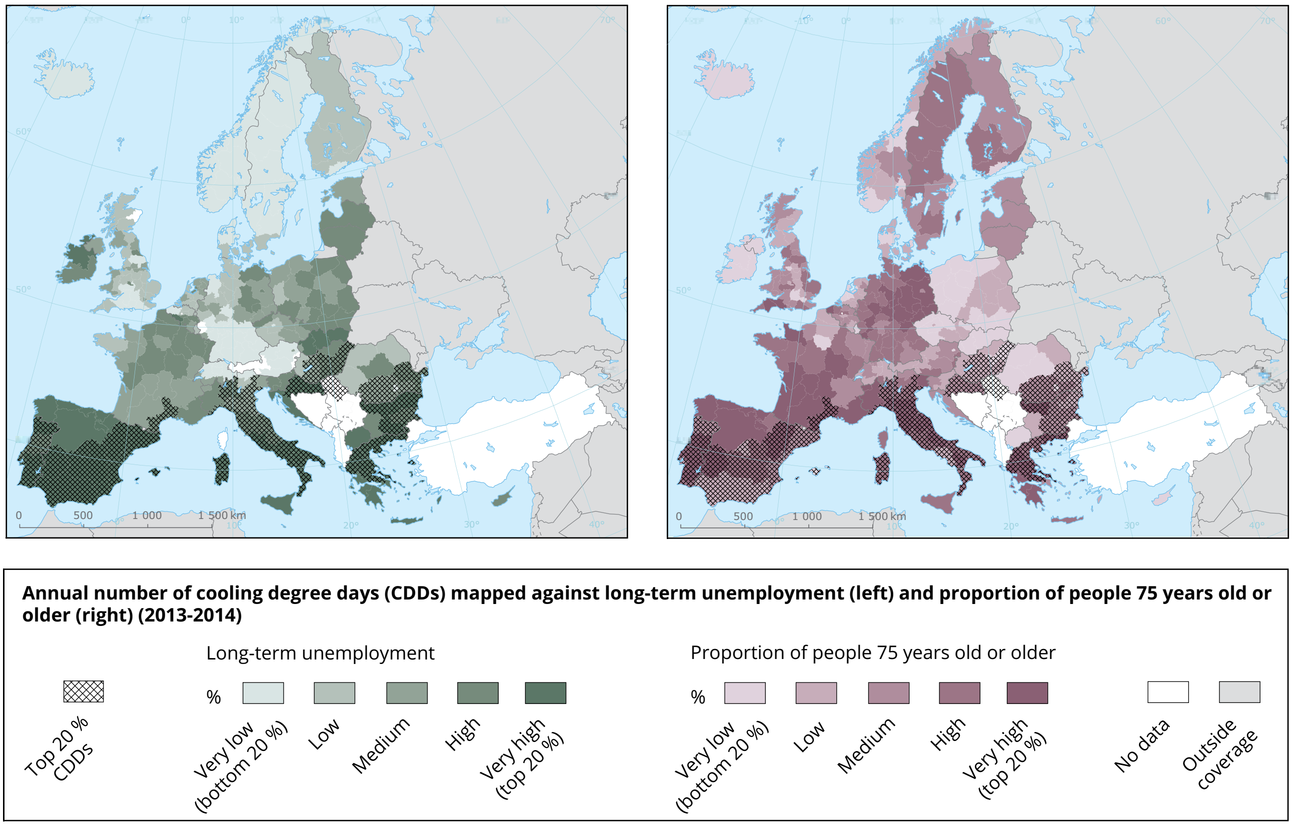
Note: SD35, number of days with maximum temperature above 35 °C per year (average 1987-2016); SD30TN20, number of combined days with maximum temperature above 30 °C and minimum temperature above 20 °C per year (average 1987-2016); CDD, cooling degree days per year (average 1990-2015); HDD, heating degree days per year (average 1990-2015). The shading represents the values of the Spearman's correlation coefficient, which measures association between aspects of social vulnerability and exposure to extreme temperatures (see Box 3.2). Positive values (in red) indicate that higher vulnerability tends to correspond to higher exposure levels; negative values (in blue) indicate that higher vulnerability tends to correspond to lower exposure levels. The intensity of the colour explains the strengths of the association.

Source: EEA.

For NUTS 2 regions, no association of note was observed between the percentage of elderly people in the population and SD30TN20 (considered the most dangerous to health). However, areas with a higher number of CDDs and a higher number of hot days tend to be weakly correlated with higher proportions of elderly people in the population. The 20 % of NUTS 2 regions with the highest proportion of elderly people experience, on average, 2.7 more CDDs a year than the 20 % of the NUTS 2 regions with the lowest proportion of elderly people (113 and 42 CDDs, respectively). Therefore, heat stress for the elderly is concentrated in Greece, Italy, Portugal and parts of Spain (Map 3.7). This only partially overlaps with the spatial distribution of heat-related fatalities (see Map 2.3): south-eastern countries recorded few fatalities, whereas France had many thousands of fatalities. This could be explained, to an extent, by the lack of correlation between the proportion of elderly people and the number of hot days/warm nights, which are considered most dangerous from a health perspective (Murage et al., 2017). Limitations associated with recording fatalities linked to weather extremes (including the big impact of the 2003 heatwave), or the data presentation in Map 2.3 (absolute numbers not reflecting the size of the country's population) may also play a role.

In Europe, the areas characterised by a higher number of HDDs overlap spatially with the regions with lower levels of unemployment. In addition, the areas with higher potential demand for heating are also characterised by a lower number of the elderly in the population. This suggests that the problem of social vulnerability to cold temperatures in Europe may be less acute than the issues of heat stress. Nonetheless, as highlighted in Section 2.4.3, there remains a large number of people unable to keep their homes adequately warm as a result of building quality and affordability of energy, and fatalities associated with extremely low temperatures continue to happen, as illustrated by the cold wave of early 2018.

Map 3.7 **Annual number of CDDs mapped against long-term unemployment (left) and proportion of people 75 years old or older (right).**



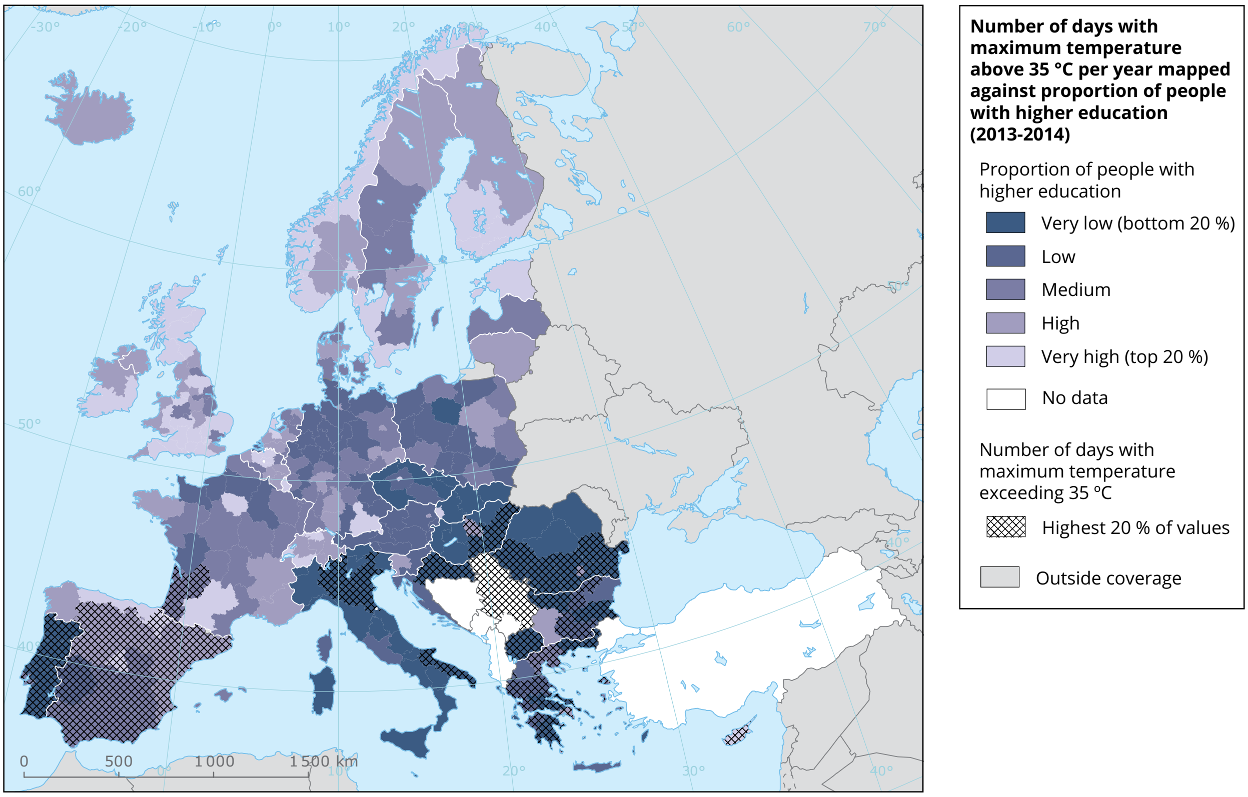
Note: Number of cooling degree days per year is the 1990-2015 average. The long-term unemployment rate and the percentage of people 75 years old or older are classified using quantiles, i.e. five equal intervals. Mapped for NUTS 2 regions.

Source: EEA based on the E-OBS dataset (updated from Haylock et al., 2008) and Eurostat.

3.5 Exposure of vulnerable regions to multiple hazards

The exploratory assessment in this chapter has revealed that areas with high social vulnerability spatially overlap with the occurrence of multiple types of hazard. Map 3.9 presents a count of environmental health hazards that substantially affect a given NUTS 2 region and therefore place it in the top 20 % in Europe in terms of exposure. The environmental health hazards considered include exposure to PM_{10}, NO_2, O_3, the number of CDDs and the number of HDDs ([21]). The most exposed regions are located in Italy and suffer from all three types of air pollution as well as high temperatures. The regions where the population is substantially affected by three out of five hazards are located mainly in Greece, Italy and Spain (no regions in the north or north-west of Europe are substantially affected by more than two hazards).

Map 3.8 Number of days with maximum temperature above 35 °C per year mapped against proportion of people with higher education.



Note: Number of days with maximum temperature above 35°C per year is the 1987-2016 average. Proportion of people with higher education is classified using quantiles, i.e. five equal-size intervals. Mapped for NUTS 2 regions.

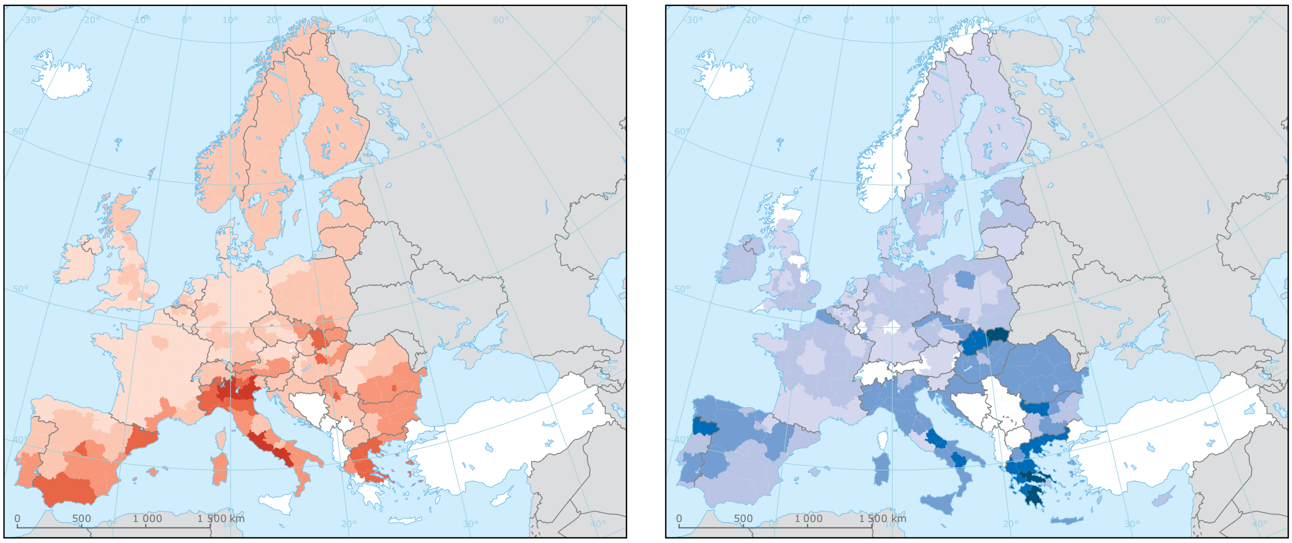
Source: EEA based on the E-OBS dataset (updated from Haylock et al., 2008) and Eurostat.

([21]) $PM_{2.5}$ was not included because of a high correlation with PM_{10}. The proportion of people exposed to high levels of road noise was excluded because of data missing in a large number of NUTS 2 regions.

Map 3.9 (below) shows the count of underlying causes of social vulnerability of the following: percentage of children under 5 years old in the population; percentage of people 75 years old or older in the population; average household income; percentage of long-term unemployed in the working age population; and percentage of people without higher education. There are some regions with four out of five causes of vulnerability in the top 20 % across Europe; low levels of income and education, and high unemployment overlap with high proportions of elderly people (Greece) or young children (Slovakia). The regions where substantial levels of three different causes of vulnerability occur together are mainly located in Greece, Hungary, parts of Italy, Slovakia, and individual regions in Bulgaria and Portugal. No regions with more than two high levels of vulnerability causes are present in the north and north-west of Europe. On the contrary, there are hardly any NUTS 2 regions in the south-east of Europe that would not be in the top 20 % for at least one cause of vulnerability. The regions where the highest number of causes of vulnerability overlaps with the highest number of hazards are mainly present in Greece, Italy and Slovakia.

Therefore, a division can be seen between the south-east and the north-west of Europe in terms of the number of temperature- and air pollution-related hazards coinciding with populations that are vulnerable for multiple reasons. This shows that the disparities in Europe are not only present in socio-economic terms (EC, 2017c) but that the inequalities are also redrawn in relation to environmental justice.

Map 3.9 Multiple hazards and multiple causes of vulnerability in Europe



Multiple hazards and multiple causes of vulnerability in Europe

Number of hazards in top 20 %

0 1 2 3 4

Number of vulnerability causes in top 20 %

0 1 2 3 4

No complete data

Outside coverage

Note: The map presents the number of environmental health hazards or causes of vulnerability for which a given NUTS 2 region was classified in the top 20 % in Europe.

Source: EEA.

4 Policies addressing the inequalities in exposure to and impacts of environmental health hazards

Key messages

- Multiple international strategies, such as the United Nations Sustainable Development Goals, the Paris Agreement, Sendai Framework for Disaster Risk Reduction and WHO health strategies, recognise the need for policy and action to focus on the protection of the most vulnerable groups in society against environmental health hazards.
- The key European policies — the 7th EAP, EU adaptation strategy and the air quality and noise directives — mention the need to protect vulnerable groups from pollution and extreme temperatures.
- The policy framework does not explicitly include actions targeting vulnerable groups but focuses on ensuring a good-quality environment for all, rather than addressing inequalities.

4.1 International sustainability frameworks

At a global level, the United Nations (UN) Sustainable Development Goals (SDGs) (UN, 2015) aim to address a broad range of social, economic and development issues including, among others, fighting poverty, achieving good health and well-being for all, reducing inequalities and building sustainable cities and communities, as well as promoting climate action. The scale and breadth of the issues that the SDGs aspire to tackle highlight the linkages between socio-demographic factors and environmental protection. For example, fighting poverty (SDG 1) cannot be achieved without promoting well-being and health for all (SDG 3) and without reducing inequalities (SDG 10), including unequal access to health services. Moreover, climate action (SDG 13) is key to protecting more vulnerable people from climate risks, such as extreme temperatures. One of the targets for SDG 1 is to 'build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters' by 2030. It is recognised that exposure to noise and air pollution exacerbates the risks to health, particularly among poorer and more vulnerable populations, and this can constitute a further obstacle to inclusive and sustainable economic growth (SDG 8). It is stressed that the linkages need to be addressed holistically, i.e. by addressing environmental, social and economic concerns in an integrated way and in line with the principles of sustainable development. For example, sustainable city planning (SDG 11) is one of the driving forces behind building resilient communities.

With regard to cities, the UN Habitat III New Urban Agenda lays out how cities should be planned and managed to best promote sustainable urbanisation (UN Habitat, 2016). The document lists air quality among the public goods and quality services that everyone should have equal access to (UN Habitat, 2016). It puts a strong focus on 'sustainable urban development for social inclusion and ending poverty' and 'environmentally sustainable and resilient urban development', recognising the social risks of climate change and the need for adaptation measures to be inclusive.

The 2015 Paris Agreement on Climate Change (UNFCCC, 2015) recognises the importance of considering the rights of vulnerable people (including local communities, migrants, children and people with disabilities) when taking action to address climate change. Specifically on adaptation, Article 7.5 states that 'adaptation action should follow a country-driven, gender-responsive, participatory and fully transparent approach, taking into consideration vulnerable groups, communities and ecosystems'. Furthermore, WHO recognises the co-benefits of the Paris Agreement to public health, as reducing the use of fossil fuels would also reduce air pollution (UNFCCC, 2018).

The Sendai Framework for Disaster Risk Reduction bears relevance to heatwaves. The framework specifically addresses vulnerable populations. It calls for, among others things, '... more dedicated action ... to be focused on tackling underlying disaster risk drivers, such as the consequences of poverty and inequality, climate change and variability, unplanned and rapid urbanization' (UNISDR, 2015, Article 19(d)). The framework calls for the integration of disaster risk management action with policies for sustainable development and poverty eradication, aiming at community resilience. In addition, with 'understanding disaster risk' as its first priority, it also focuses on '... understand[ing] the economic, social, health, education, environmental and cultural heritage impacts, as appropriate, in the context of event-specific hazard-exposure and vulnerability information' (UNISDR, 2015).

The interaction between health inequalities, and social and environmental determinants is clearly considered by the Health 2020 strategy for the WHO European region (WHO Europe, 2013c). The strategy includes the social and environmental dimensions among the determinants of health and health inequalities, and it highlights that health inequalities can feed into further inequities in exposure to pollution. Through its pan-European Environment and Health Process it addresses environmental and climate-related threats to human health, particularly to children. A WHO Europe (2017) report, monitoring countries' progress towards the Health 2020 strategy targets in the European region ([22]), indicates that environment is increasingly included in national health strategies. In 2016, 86 % of the European region countries included the environment in their national health strategies as one of the determinants of health; 91 % aimed to improve the health of disadvantaged groups in their strategies. The extent to which the quality of environment is considered in combination with deprived groups in these strategies is unknown but, including both the environment and deprivation in national health strategies provides an opportunity for improving the environment for the most deprived groups.

In addition, the Declaration of the Sixth Ministerial Conference of Environment and Health, adopted in June 2017 by the environment and health ministers of all Member States in the WHO European region, emphasises the relationship between exposure to noise and air pollution, and social vulnerability. The signatories note that pollution and environmental degradation disproportionately affect socially disadvantaged and vulnerable population groups. In the annex accompanying the Declaration, ministers have pledged to consider the social determinants of health and to integrate environmental and social policies to reduce socio-economic inequalities. For example, health, environmental and equity targets should be integrated into sectoral policies, like housing, transport or land use, to address inequalities (WHO, 2017).

4.2 EU policies

4.2.1 European sustainability and environmental strategies

The 7th EAP, *Living well, within the limits of our planet* (EC, 2013f), contains nine priority objectives; objective 3 is 'to safeguard the Union's citizens from environment-related pressures and risks to health and well-being'. The document stresses that, in order to achieve an inclusive and green economy, the interplay between socio-economic and environmental factors needs to be properly considered. With regard to air quality, the 7th EAP highlights that policies need to focus on areas where people who are particularly sensitive, or vulnerable groups of society are exposed to high levels of pollution. However, the document does not define sensitive or vulnerable groups. In the case of noise, the 7th EAP's focus is on whole population exposure and its objective is to 'significantly decrease noise pollution in the Union, moving closer to WHO recommended levels'. Similarly, in relation to climate change adaptation, no special consideration is given to vulnerable groups.

The European Commission's Communication Next steps for a sustainable European future. European action for sustainability directly relates the EU's objective of a sustainable future to the UN's SDGs and states that 'existing and new policies should take into account the three pillars of sustainable development, i.e. social, environmental and economic concerns' (EC, 2016a, p. 18). Progress towards the SDGs, in the EU context, is monitored by using a set of 100 indicators, 41 of which are 'multi-purpose', meaning they are used to monitor more than one goal. This allows a link between different goals to be highlighted (Eurostat, 2017b). For example, indicators measuring exposure to air pollution and noise are applied in measuring progress towards SDG 3 (ensure healthy lives and promote well-being for all at all ages) and SDG 11 (sustainable cities and communities) and

([22]) The report covered 43 countries in the WHO European region.

therefore emphasise the role that a good-quality environment plays in social well-being. However, the uneven exposure of different groups to air pollution and noise, or the uneven impacts of extreme temperatures on different groups, are not measured.

The EU strategy Green infrastructure (GI) — Enhancing Europe's Natural Capital emphasises that green infrastructure can be helpful in mitigating the UHI effect and reducing the risks of high temperatures for vulnerable groups, such as those who are chronically ill or the elderly (EC, 2013d). However, no similar observations are made in relation to mitigating exposure to air pollution or noise and their effects. The strategy also underlines that implementing green infrastructure, especially in urban areas, would lead to a greater sense of community, strengthen the link with voluntary actions undertaken by civil society and help combat social exclusion and isolation.

Neither the Environmental Impact Assessment (EIA) nor the Strategic Environmental Assessment (SEA) Directives (EU, 2001, 2014) address the distributional impacts of projects on society. In both pieces of legislation, human health is just included as one of the elements that should be considered in the assessment. In some countries (e.g. Scotland), the translation of the SEA Directive into national legislation and its implementation was accompanied by a debate on the extent to which the EU requirements could be extended to include environmental justice concerns (Walker, 2010). According to Connelly and Richardson (2005), SEA could play a role in addressing the disproportionate exposure of vulnerable and disadvantaged groups to environmental health hazards, but multiple questions arise with regard to both the process of assessment and the potential uses of its outcomes (Walker, 2010).

4.2.2 *Policies on air quality, environmental noise and extreme weather events*

The air quality legislation takes the approach of limit values applicable across the EU to guarantee a minimum standard of air quality. Air Quality Directives generally recognise that some groups can be particularly vulnerable to environmental impacts. The Ambient Air Quality Directives (AAQ) (EU, 2008, 2004) include references to sensitive population groups, including children and older people. Directive 2008/50/EC on ambient air quality and cleaner air for Europe (EU, 2008) establishes an information threshold for O_3, so that sections of the population particularly sensitive to concentrations above that threshold can be informed immediately and appropriately. Moreover, it requires an evaluation of the estimated number of people exposed to poor air quality when developing an air quality management plan and encourages specific measures aiming to protect sensitive population groups, including children, when implementing short-term action plans. However, socio-economic factors have not been included in the Directive as a topic for consideration when developing air quality plans. The National Emission Ceilings Directive (NEC) (EU, 2016a), the Medium Combustion Plants Directive (EU, 2015) and the Industrial Emissions Directive (EU, 2010) do not mention the vulnerability of citizens. Overall, air quality legislation is more focused on emission standards rather than on the exposure of the population to air pollutants (EEA, forthcoming). Crucially, the assessment of the effectiveness of EU legislation on air quality by the European Court of Auditors (ECA) concluded that it did not deliver the expected impact with regard to protecting human health, mainly because most Member States did not effectively implement the AAQ Directive (ECA, 2018).

The END (EU, 2002) requires Member States to include in their action plans 'an evaluation of the estimated number of people exposed to noise, identification of problems and situations that need to be improved'. Annex IV on minimum requirements for strategic noise mapping states that 'a strategic noise map is the presentation of data on one of the following aspects: the estimated number of dwellings, schools and hospitals in a certain area that are exposed to specific values of a noise indicator'; therefore, it offers the option of providing data on facilities catering for vulnerable groups. In addition, it states that 'if necessary, specific dose-effect relations could be presented for vulnerable groups of the population'. However, it does not specify who should be treated as vulnerable and when the necessity to consider these groups should arise.

The EU Civil Protection Mechanism (EC, 2013e), which may be relevant in the case of prolonged spells of high or low temperatures, does not mention vulnerable groups and neither does the European Commission communication Strengthening EU disaster management; rescEU Solidarity with Responsibility (EC, 2017b). Looking forward, the EU strategy on adaptation to climate change (EC, 2013c) explicitly recognises that 'climate change impacts are expected to widen social differences across the EU' and emphasises that special attention needs to be given to 'social groups and regions which are most exposed and already disadvantaged (e.g. through poor health, low income, inadequate housing, lack of mobility)'. The strategy package includes a communication from the European Commission and accompanying documents, as well as the EU guidelines on developing adaptation strategies, which also mention the consideration of particularly vulnerable social groups. The evaluation of the adaptation strategy (EC, 2018b) highlights the areas where the strategy may be able to deliver more in the future, including:

- Promoting the assessment of social vulnerability to climate-related events and involving vulnerable groups for the design of fair adaptation policies.
- Reinforcing the links between public health and adaptation, to address current and emerging climate-related health risks.

4.2.3 Social vulnerability to environmental health hazards in other European policy areas

Cohesion policy

EU cohesion policy is the EU's main investment policy, contributing to the Lisbon Treaty's objective of reducing economic and social disparities in Europe. Although the thematic objectives supporting growth for the period 2014-2020 include 'promoting climate change adaptation, risk prevention and management' and 'promoting social inclusion, combating poverty and any discrimination' (Thematic Objective 5), there are no specific funds addressing socio-environmental inequalities. In spite of climate change impacts on vulnerable population, European Social Fund (ESF) does not specifically address Thematic Objective 5 (EC, 2018b).

Cohesion funds regarding air and noise pollution are also limited; less than 1 % of EU cohesion funding is directly allocated to air quality measures, although other cohesion policy actions can indirectly benefit air quality (ECA, 2018). According to the Urban Poverty Partnership under the EU Urban Agenda, EU funds are not sufficiently allocated to effectively address specific areas e.g. deprived urban neighbourhoods (Urban Poverty Partnership, 2018) where social and environmental problems are concentrated. However, 'vulnerable regions and citizens' are supported through indirect contributions, potentially beneficial to clean air, from the 2014-2020 European Structural and Investment Funds' investments in the low-carbon economy, environmental protection, resource efficiency and network infrastructure (EC, 2018a).

Territorial and growth policy

The Territorial Agenda 2020 (EC, 2011b) states that the impacts of climate change vary considerably across Europe as a result of different hazards and vulnerabilities present in geographical regions. The document explicitly states that environmental quality, including air pollution and noise, in certain cases correlates with social inequality (p. 5). Furthermore, socio-economic factors are also considered to be linked to territorial segregation — when this is translated into barriers to effective and sustainable transport connections, low accessibility of services, limited access to natural resources, ecological fragmentation and diminished social capital, it clearly demonstrates how some of the factors are linked to health and exposure to pollution (p. 8).

Europe 2020 — a strategy for smart, sustainable and inclusive growth (EC, 2010) sets ambitious poverty, climate change and resource efficiency targets, and recognises the need to design interventions to support vulnerable groups, such as lone parent families, elderly women, minorities, the Roma community, people with a disability and the homeless (p. 19). However, the interplay between these issues seems to be overlooked.

Health

Equity in health is one of the fundamental values of the EU health strategy (EC, 2007), which helps to reduce health inequalities through various activities in order to strengthen health systems, disease prevention and health promotion. The strategy intends to combat health threats and contribute to other EU policies that have an impact on health, with the aim of ensuring that they contribute to a high level of health protection for everyone (EC, 2013b). Solidarity in health: reducing health inequalities in the EU (EC, 2009) lists environmental policy as one of the mechanisms that can help to lessen health inequalities between and within Member States.

Urban issues

The 2016 Urban Agenda for the EU (EU, 2016b) considers urban poverty, climate adaptation and air pollution among its 12 priorities and includes social, economic and environmental aspects as cross-cutting issues (p. 7) The Urban Agenda for the EU acknowledges the structural dimensions of poverty in deprived urban neighbourhoods and calls for integrated approaches to urban regeneration, with a focus on air pollution and the social dimension of climate adaptation strategies. The agenda promotes integrating different aspects of policy to avoid contradictory consequences; however, the extent to which this will be achieved by the 12 separate thematic partnerships remains to be seen, as the thematic action plans were still being prepared at the time of writing.

Energy

Section 2.4.3 emphasises the importance of thermal comfort at home for health. Affordable energy may help to ensure that those on low incomes and those most affected by temperature extremes, due to age or illness, are able to pay for indoor heating or cooling during periods of extreme temperatures. While finding alternative ways of keeping cool or warm are necessary considering the need to reduce energy use and greenhouse gas emissions, securing vulnerable groups' access to energy will continue to be essential. Box 4.1 outlines how the current EU legislation addresses this issue.

In summary, a number of key international policies and agreements recognise the social impacts of environmental health hazards and call for consideration of vulnerable groups and locations to protect them from disasters and ensure sustainable development for all. However, the current suite of EU environmental, sustainability and relevant sectoral policies presents a mixed picture of the consideration given to vulnerable members of society. As a baseline, the EU treaties and cohesion policy aim to reduce inequalities. Importantly, the directives and strategies related to air quality, noise and climate change, and the general environmental and sustainability strategies consider the differing vulnerability of people as a result of socio-demographic factors. Furthermore, the health and energy policies firmly focus on social inequalities and protecting vulnerable groups. However, some key documents (7th EAP, END) do not specify who the vulnerable groups are. The air and noise directives do not require specific and preferential actions aimed at lessening the exposure of vulnerable groups. In addition, in many key areas the social and environmental problems still tend to be considered separately, for example, in cohesion funds, indicators used to measure progress towards SDGs in Europe or the development of action plans under the EU Urban Agenda.

Box 4.1 Ensuring access to energy for vulnerable consumers through EU policies

The Electricity and Gas Directives (EU, 2009a, 2009b) require each Member State to define vulnerable customers according to their own particular situation and to ensure that there are adequate safeguards to protect their access to energy. The Vulnerable Consumer Working Group guidance document (EC, 2013g) provides an overview of the legislative acts relevant to vulnerable customers in the context of energy, drivers of vulnerability and the explanation and overview of Member State instruments and practices ensuring affordability of energy to all.

The Energy Roadmap 2050 (EC, 2011a) highlights the social dimension that EU policymakers have to consider in their pursuit of a new energy system and that measures should be designed at national and local levels to avoid energy poverty. Although there is increasing concern, from an air quality perspective, surrounding the potential rise in the use of solid fuels as a response to energy poverty (Air Quality Expert Group, 2017), the Roadmap does not directly deal with this issue.

Also, the more recent Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy (EC, 2015b) sets out the vision of an Energy Union 'with citizens at its core ... where vulnerable consumers are protected' (Article 1). The strategy emphasises that heating and cooling of buildings is the single largest source of energy demand in Europe and it draws attention to the needs of those living in energy poverty due to 'a combination of low income and general poverty conditions, inefficient homes and a housing tenure system that fails to encourage energy efficiency' (Article 2.2). The strategy also stresses that energy poverty can be tackled only by a combination of measures, mainly in the social field and by national, regional or local authorities. Affordability of energy for vulnerable groups while phasing out regulated prices can be ensured by solidarity tariffs or discounts on energy bills, for example. Delivering a new deal for energy consumers (EC, 2015a) describes measures targeting energy poverty, including consumer empowerment, and smart homes and networks.

The European Commission's proposal for a revised Electricity Directive (EC, 2017d) and the recently adopted Energy Union Governance Regulation (2018) require Member States to define and measure energy poverty, to monitor its levels and to biennially report on measures to prevent it. If a Member State discovers that it has a significant number of households in energy poverty, it should formulate a national indicative objective to reduce energy poverty and include a timeframe for when this will be met as part of its integrated national energy and climate plans under the Energy Union Governance Regulation.

5 Responding to inequalities in exposure and impacts in practice

Key messages

- Responses limiting exposure to air pollution tend to be targeted at the whole population and thus benefit disadvantaged groups to varying extents. Measures, such as reducing road traffic emissions through creating low-emission areas or congestion-free zones may reduce inequalities in exposure if they are targeted at areas where vulnerable groups reside.
- There are limited examples of measures limiting vulnerable groups' exposure to noise, the existing ones focusing mainly on children.
- Examples of actions aimed at reducing the impacts of extreme temperatures on vulnerable people include identifying vulnerable groups through mapping; developing heatwave and cold wave action plans; improving housing and neighbourhoods; and community-driven initiatives providing help to vulnerable people during extreme weather events.
- Active mobility initiatives, nature-based solutions and housing improvements are identified as the types of responses to the combined problems of air pollution, noise and extreme temperature that can particularly benefit vulnerable groups.

5.1 Air pollution

Air quality in Europe has improved markedly over the years (EC, 2017c). However, little is known about the distributional effects and public health equity outcomes of pollution control (Wang et al., 2016). The impact of reducing air pollution levels on the inequality of exposure among socio-demographic groups varies for different pollutants and between different locations (Box 5.1). Likewise, the changes in relative exposure of different groups are driven not just by the changes in air pollution but also by the socio-demographic dynamics. Consequently, local measures are needed to address persisting inequalities, especially in the context of incomplete implementation of European policies aiming at lowering the overall air pollution levels. Such local measures include targeting air pollution levels in areas of higher social vulnerability or offering particular protection to vulnerable groups (EC, 2016b). They can be divided into the following types, described in more detail below:

- managing road traffic and congestion in areas occupied by vulnerable groups;
- land-use planning, aiming to decrease emissions of air pollutants, reduce socio-economic contrasts within a city and reduce exposure of vulnerable groups;
- a ban on certain domestic heating fuels, which in some locations (e.g. in central Europe) are responsible for a significant amount of air pollution (WHO Europe, 2015);
- ad hoc measures, such as short-term action plans.

Box 5.1 Absolute and relative change in exposure of groups of different vulnerability

Despite decreasing levels of air pollution across Europe, the difference in exposure to O_3 and PM_{10} between the most and least vulnerable NUTS 2 regions has increased over time, making the inequalities worse. In 2005-2006 (average over two years), the top 20 % of NUTS 2 regions with the highest long-term unemployment rate were exposed to 1.4 times more O_3 than the bottom 20 % with the lowest rate. In 2013-2014, this ratio had increased to 1.7; a similar level of change was observed with regard to O3 exposure in areas with different proportions of older people in the population. However, it is important to observe that, even where the most vulnerable regions have become relatively more exposed when compared with the least vulnerable ones, the actual level of pollution exposure has still fallen over time. In terms of $PM_{2.5}$ and NO_2 exposure, both relative and absolute measures of inequality across vulnerability levels have remained similar over time, or have even changed in favour of the most vulnerable regions (ETC/ACM, 2018).

At national level, the situation can be different, as in the case of the United Kingdom. While air pollution levels have been declining, the rate of improvement of the annual average NO_2 concentrations in the United Kingdom during the period 2001-2011 was slower for more deprived people; the NO_2 concentrations in all the most affluent areas dropped below EU exceedance limits, but this was achieved only for 70% of the poorest areas. Conversely, annual average PM_{10} concentrations have risen and have done so more quickly in the poor areas (Mitchell et al., 2015). At a local level, however, a modelling study in Westminster, London, suggests that reducing air pollution in general would decrease inequities, as levels of exposure would decrease most significantly in deprived areas and those who would benefit the most include people with poor health, young children and the elderly (Mindell and Joffe, 2004).

What matters most from a health perspective is the reduction in the absolute levels of air pollution for all European citizens, which can be achieved through observing the EU limits and target values. Nonetheless, it is important to recognise the specificity of exposure and social vulnerability in a given location and address them through local measures, which can reduce inequalities.

5.1.1 Managing road traffic

Most measures currently planned and implemented by Member States in areas where the air quality limit and target values have been exceeded (under the EU Air Quality Directives) are road traffic-related measures, namely a shift in transport mode (including an expansion of bicycle and pedestrian infrastructure) and improving public transport (EEA, 2018c). In addition, measures such as low-emission zones (preventing polluting vehicles from entering) or banning diesel vehicles in cities aim to reduce NO_x emissions.

As groups of lower socio-economic status generally tend to live in areas with higher levels of air pollution associated with road traffic (see Section 2.2.3), they may benefit more than other groups from the changes in road traffic in city centres, despite not being directly targeted by these measures. In Leeds, United Kingdom, for example, city-wide improvements in air quality, resulting from lower emission cars alone (due to natural fleet removal), reduced the average difference between deprived and affluent communities' exposure to NO_2 from 10.6 µg/m^3 in 1993 to 3.7 µg/m^3 in 2005 (Mitchell, 2005). In London, modelling of the decrease in air pollution, as a consequence of the Congestion Charging Scheme (a localised scheme targeting traffic congestion), appears to have had modest benefits for air pollution levels, but greater reductions in air pollution were achieved in more deprived areas (Tonne et al., 2008). However, in Rome, the air quality and health effects of two low-emission zones, established during the period 2001-2005, were assessed and the results found that, although air pollution levels have decreased, most of the health gains were experienced by more affluent residents (Cesaroni et al., 2012), mostly because the wealthier population live near the city centre (Wang et al., 2016) (see also Section 2.2.3). Therefore, traffic management measures are not guaranteed to improve equity, although they reduce overall emissions.

Whilst creating low emission areas and banning the most polluting vehicles from the city centres has indisputable benefits for the health of those living in the targeted areas, equity issues arise when it comes to implementing these measures. It is usually the less affluent people who own older, more polluting vehicles, and so excluding such vehicles from city centres and other areas may place groups who cannot afford low-emission cars at a disadvantage, in terms of getting to work, accessing services or running a business. Travelling by public transport compared to a private car may be longer, more complex and more costly, and therefore not feasible. In London, to mitigate the impacts on disadvantaged groups, the congestion charge is subject to discounts and exemptions to people with disabilities and residents living in certain areas near the congestion charge zone (Mullen and Marsden, 2016).

Reducing road traffic by increased cycling or walking can reduce air pollution, noise and greenhouse gas emissions simultaneously, while also providing opportunities for people to be physically active. As a result, both exposure to air pollution and noise, and vulnerability linked to poor health can be lowered, which may reduce the risk of cardiovascular and respiratory diseases, type 2 diabetes, some forms of cancer and hypertension (WHO Europe, 2013c). In relation to vulnerable groups, reducing car use on school routes and walking more frequently bring significant benefits to children's health, thanks to their reduced exposure to air pollution (Alvarez-Pedrerol et al., 2017; Nieuwenhuijsen, 2016; Khreis et al., 2017). For example, in Edinburgh, United Kingdom, several schools have banned parents from dropping off their children by car at the school gates to improve road safety, reduce congestion and address air pollution (Streets Ahead, 2016). Similarly in Malmö, Sweden, the Friendly road to school project aims to encourage parents to walk or cycle to school with their young children instead of taking them by car (City of Malmö, n.d.).

However in locations where pedestrians and cyclists share the road space with car traffic, placing responsibility on individuals to take up walking or cycling involves asking them to accept an increased physical risk. Therefore, to be equitable, promoting walking and cycling, particularly among vulnerable groups, requires providing adequate infrastructure for active mobility (Mullen et al., 2014). Some of the socio-demographic groups identified in this report as vulnerable to environmental health hazards tend to be less likely to participate in cycling, e.g. (in the United Kingdom) people living in deprived neighbourhoods, those with disabilities and older people. Increasing the uptake of cycling among those groups through cycle hire or ownership schemes, tuition and engagement of local communities in planning and delivering the initiatives may be more resource intensive than actions aimed at the whole population (Transport for London, 2011).

5.1.2 Urban planning

Analysis of the progress on implementing air quality policy made by 12 European cities within the joint EEA and the European Commission Air implementation pilot project ([23]) identified some spatial planning measures, implemented by cities participating in the project, aimed at protecting vulnerable groups, in particular children. For example, in Malmö, Sweden, the development of new day-care centres for young children is allowed only in locations that comply with the national goals on air quality for 2020. In Antwerp, Belgium, schools cannot be built in areas exceeding certain NO_2 concentrations. In Vienna, Austria and Berlin, Germany environmental assessment studies evaluating air quality, are required for newly built schools. In addition, participating cities listed 'social proportionality' of any air quality management measure implemented as one of the criteria for selecting a given measure (EEA, forthcoming).

WHO Europe (2010) identifies urban planning as a crucial mechanism for reducing inequalities in exposure to air pollution. The traditional shape of some European cities, i.e. the way they are divided into zones according to different types of activity (cultural, work, residential, industrial, leisure, etc.), and land price contribute to the spatial segregation of the wealthy and the poor in a city. Such city layout also increases air pollution through traffic emissions associated with longer commutes. The WHO report advocates reshaping cities into multi-polar structures with urban clusters, or poles, equipped with housing, workplaces, commercial and cultural sites, reducing the need for commuting. Such hubs would ideally contain a range of housing options, bringing together communities of different incomes and thus reducing segregation in cities.

Another important aspect of city planning influencing exposure to air pollution is through providing and managing green space. People's respiratory health in highly polluted areas tends to improve with the expansion of tree cover (Alcock et al., 2017). The presence and type of green areas in cities, as well as access to them, influences physical and mental health, and health-related behaviour (WHO Europe, 2012). For example, more green space could potentially support the uptake of cycling in cities, as cyclists generally prefer to cycle in greener areas (Nieuwenhuijsen, 2016). Consequently, urban greening can not only help to reduce air pollution emissions from traffic but also improve the health of the people, reducing their vulnerability to environmental health hazards.

5.1.3 Equity implications of banning solid fuels in domestic heating

Air pollution in some locations can be reduced by banning the sale of certain fuel products for domestic heating. In 2010, one fifth of $PM_{2.5}$ in central Europe could be traced back to residential heating powered

([23]) https://www.eea.europa.eu/themes/air/the-air-implementation-pilot-project (accessed 29 November 2018).

by solid fuels. Solid fuels are mainly used by poorer households. For example, some households in Greece and other European countries reverted to solid fuel heating (such as discarded furniture, wood scrap and coal) during times of economic hardship (WHO Europe, 2015).

While the ban on the most polluting fuels has unquestionable air quality and health benefits, it is also associated with equity issues related to the affordability of fuel and the ability of poorer households to cope with cold temperatures, as is the case in Dublin, Ireland (Box 5.2). More recently, in Krakow, Poland (one of the cities with the highest air pollution in Europe), a resolution was adopted limiting fuels used for domestic heating to gas and light fuel oil. This will enter into force on 1 September 2019. Households affected by this resolution have to switch to gas, light fuel oil or district heating systems or to electric heating appliances.

Under the air quality programme and the resolution adopted by the City of Krakow, grants will be provided for replacing old solid fuel appliances as well as subsidies for fuels to reduce the impact on low-income households (European Parliament, 2016). A special subsidy programme was set up by the Ministry of Family, Labour and Social Policy in partnership with Polskie Górnictwo Naftowe i Gazownictwo SA (the biggest company in the Polish natural gas market), whereby families with three or more children can receive up to EUR 700 for replacing old heating appliances ([24]). However, several of the cities participating in the Air implementation pilot project (Madrid, Spain; Milan, Italy; and Prague, Czechia) highlighted the potential inequity issues linked to the exchange of boilers and stoves, as the new, cleaner appliances remain too expensive for the poorest population, even when subsidised (EEA, forthcoming).

Box 5.2 Dublin's 'smoky coal' ban: equity issues

In September 1990, the Government of Ireland banned the marketing, sale, and distribution of bituminous coals within the city of Dublin. A comparison of periods lasting 72 months before and after the ban on coal sales in Dublin revealed that average black smoke (a measure of ambient particles) concentrations had declined by 35.6 mg/m^3 (70 %) after the ban. About 116 fewer respiratory deaths and 243 fewer cardiovascular deaths attributable to air pollution were seen per year after the ban, with the greatest reduction in deaths among people over the age of 60. Therefore, groups considered vulnerable because of their age benefited most from the ban.

However, the ban also had some negative economic equity consequences; while the average weekly household expenditure on energy declined between the years 1987 (pre-ban) and 1994 (post-ban), this decrease was smaller in Dublin than in other areas, which suggests that Dublin residents were bearing higher energy costs due to the ban. Also, while the wealthier Dublin residents switched to gas (and were expected to make long-term savings in their energy expenditure), poorer residents were forced to choose cheaper oil and the poorest households carried on burning non-banned solid fuels, consequently experiencing a long-term increase in costs for these more expensive fuels. To mitigate this impact, the government provided a weekly smokeless fuel allowance to qualifying households during the winter months. The additional national cost of these payments was over EUR 20 million.

Building on these experiences, a nationwide ban on 'smoky coal' will be introduced in Ireland incrementally from autumn 2018, with a full ban coming into effect from autumn 2019. Thus, Ireland will become the first EU country to completely ban 'smoky coal'.

Sources: Clancy et al. (2002); Clinch and Healy (2001); Jones et al. (2005).

([24]) https://www.mpips.gov.pl/aktualnosci-wszystkie/swiadczenia-rodzinne/art,9851,pgnig-partnerem-karty-duzej-rodziny.html

5.1.4 Ad hoc measures targeting vulnerable groups

Article 24 of the Directive on ambient air quality and cleaner air for Europe (EU, 2008) requests that Member States draw up short-term action plans where there is a risk of exceeding one or more of the limit or target values. For PM_{10}, for example, such measures can include reducing vehicle speeds, driving bans for specific types of vehicle, limiting domestic or commercial heating emissions and cleaning the streets. The analysis of 39 short-term action plans from 14 Member States indicates that only some of the plans provide information for specific sensitive population groups (e.g. young children) when information or alert thresholds are exceeded. Generally, vulnerable groups were advised to avoid exercise and stay indoors to minimise their exposure. However, none of the short-term action plans examined included measures to reduce concentrations in places where vulnerable people spend their time (e.g. schools or hospitals) (Conlan et al., 2012). Therefore, the use of this instrument for protecting vulnerable groups could be further explored.

Another ad hoc measure specifically targeting vulnerable groups is providing air purifiers. In Poland, Warsaw City Council has promised air purifiers for all 350 kindergartens in the city, at a cost of EUR 930 000, in an attempt to address the acute problem of smog. The air purifiers have already been in operation for several years in 72 nurseries and day-care centres for the youngest children in Warsaw ([25]). Research suggests that mechanical air filtration can indeed reduce indoor exposure to traffic-related air pollution. The use of high-efficiency particulate air filters reduced indoor $PM_{2.5}$ concentrations by 60 % in one study (Allen et al., 2011). However, filtration is only effective if the filters are frequently replaced and the ventilation system is properly maintained, otherwise it may pose additional health risks (Zee et al., n.d.). Furthermore, some types of filters require the use of electricity, thus their application may not be sustainable in the long term.

5.2 Noise

WHO sets guidance values for specific environments used by sensitive groups of people. For instance, noise levels in school playgrounds should not exceed 55 dB LAeq ([26]), whereas indoor classroom noise levels should not exceed 35 dB LAeq (Berglund et al., 1999).

The Night Noise Guidelines (WHO Europe, 2009) set a night-noise health-based recommended threshold of 40 dB L_{night} to protect the public, including most of the vulnerable groups such as children, the chronically ill and the elderly, from the adverse health effects of noise. These values are considered in some countries' building regulations or by infrastructure developers when conducting an environmental impact assessment. For example, acoustic design and planning for noise-sensitive buildings is captured in guidance documents such as Acoustic design of schools: performance standards (Department for Education and Education Funding Agency, 2015) in the United Kingdom. However, noise mitigation measures targeted specifically at protecting vulnerable people from environmental noise are rarely implemented. The recently published Environmental noise guidelines for the European region (WHO Europe, 2018a) nominates exposure levels at which cognitive effects on children certainly begin. The guidelines conclude, based on available evidence, that risk of impaired reading and comprehension in children increases at 55 dB L_{den}.

Nonetheless, there are examples of actions aimed at protecting children from noise, as a particularly vulnerable group. For instance, the United Kingdom Aviation Policy Framework 2013 (TSO, 2013) stipulates that airports are expected to provide acoustic insulation or alternative mitigation measures to schools exposed to high levels of aircraft noise. The most frequently used mitigation measures for schools include providing double glazing. However, this can pose some problems during the summer when windows need to be open for ventilation. An additional approach used by Heathrow Airport, United Kingdom was providing financial support for shelters in school grounds to reduce noise during outdoor lessons or during breaks. Several schools located directly under the flight paths of Heathrow's runways installed shelters constructed from long tubes filled with soil (with plaster walls), which may reduce overhead aircraft noise by 17 dB for pupils inside (Heathrow Airport Limited, 2013).

Another example of intervention aimed at reducing the impact of noise on children, adolescents and the elderly in a busy urban setting is the redesign of Nauener Platz in Berlin, Germany. The square is located between busy roads and the construction of 1.5 m high stone walls around the perimeter has helped to reduce the noise levels by 6 dB. In addition, 'audio islands', i.e. benches playing birdsong and water sounds, were installed

([25]) http://www.um.warszawa.pl/aktualnosci/warszawa-zamontuje-oczyszczacze-powietrza-we-wszystkich-przedszkolach (accessed 29 November 2018).

([26]) The LAeq is defined as the equivalent continuous sound level. It is an average over a stated period of time, using A-weighted frequency response.

throughout the park, as using natural sound to improve the sound environment has been proven to improve the perception of noise (ten Brink et al., 2016).

There are other noise mitigation measures related to urban planning that could help to protect some vulnerable groups. For example, Riedel et al. (2018) suggest that dwelling-related environmental resources, such as having access to a quiet side and green space, influence both perceived noise control and noise annoyance in the elderly. More knowledge is needed on the impacts of noise on vulnerable groups to highlight the need for developing specific actions aimed at them (see also Section 6.3.3).

5.3 Extreme temperatures

A review of relevant case studies within Climate-ADAPT ([27]), a request for information from member countries and organisations working directly with local authorities (Local Governments for Sustainability (ICLEI) and Covenant of Mayors) and a literature search helped to identify the following five types of policy and action measures that are focused on reducing the impacts of high and low temperatures on various vulnerable groups:

- identifying vulnerable people and communities through mapping to inform policy and action;
- heatwave and cold wave response plans originating in the public health sector;
- adaptation to climate change strategies and plans;
- actions aimed at reducing exposure to heat through improvements to the living environment (housing and neighbourhood) and also through urban planning;
- community-driven self-help initiatives.

5.3.1 Identifying vulnerable people and communities

Decision-making about targeting action and resources towards different areas can be based on geographical mapping of locations where vulnerable populations concentrate within a country, region or city. In the United Kingdom, research projects funded by the Joseph Rowntree Foundation resulted in the development of a portal focused on climate justice issues: Climate Just ([28]) includes a map tool, which shows the extent of social vulnerability, the projected high temperature risks on a neighbourhood scale and current fuel poverty. The project was followed by several initiatives across the United Kingdom and, as a result, all four devolved administrations in the United Kingdom have spatial assessments of social vulnerability, which were used as evidence in the United Kingdom Climate Change Risk Assessment 2017 (Street et al., 2016). The results have been applied by individual local authorities (e.g. Wigan and Newcastle) to identify areas particularly vulnerable to climate impacts because of the characteristics of the population (ETC/CCA, 2018). A similar approach was followed in other locations, including Trnava and Košice in Slovakia, where mapping was done at a much finer spatial scale and was supplemented by surveys with residents (Climate-ADAPT, 2018).

Despite high temperatures mainly affecting southern Europe (see Section 3.4), some evidence suggests that people living in cooler climates may be more sensitive to sudden temperature increases (WMO and WHO, 2015). The case study of Botkyrka (Box 5.3) demonstrates how mapping of social vulnerability to heatwaves has been used in adapting to increasing temperatures in Sweden. However, it is worth emphasising that top-down assessments of vulnerability (e.g. through area-based indicator mapping) may not be accurate, especially for small communities, where a more qualitative approach is needed to identify vulnerable groups (see also ETC/CCA, 2018).

([27]) https://climate-adapt.eea.europa.eu/knowledge/tools/sat (accessed 29 November 2018).
([28]) https://www.climatejust.org.uk (accessed 29 November 2018).

Box 5.3 Addressing social vulnerability to high temperatures in Botkyrka, Sweden

In summer 2018, Botkyrka, a city of 92 000 inhabitants located south of Stockholm, was affected by a long heatwave with temperatures rising above 30 °C over many days. The city could, however, cope relatively well with the impacts, as it had learned from an earlier heatwave in 2010. At that time, a residential home for the elderly was seriously affected because it faced south-west and lacked a cooling systems. The residents felt unwell and the staff struggled to provide the usual quality of care. In addition, pre-school institutions were affected by high indoor temperatures and a lack of shading in outdoor areas.

During the period 2006-2011, Botkyrka participated in the Climatools research programme of the Swedish Defence Research Agency. The homes of residents over 80 years old, recipients of health and social care, those on certain medicines, those suffering from pulmonary diseases, mental illness and diabetes were all identified. This involved using information from registers on population, medicine, patients, and health and social care and close collaboration between the departments of statistics, environment and social care. The mapping showed that one quarter of Botkyrka's population was particularly sensitive to heatwaves. Only 7 % of these people received health or social care, which emphasises that social care data alone would not present a full picture of social vulnerability.

Information produced by the project raised awareness of heatwaves among health and social care providers and other relevant stakeholders, who received advice and checklists for procedures. Consequently, routines for people in elderly care were already in place when the 2018 heatwave happened. Staff made more frequent visits to recipients of care living in their own homes. Furthermore, an emergency group was established in July 2018, bringing together representatives from all municipal committees and a municipal real estate company, which owns 10 000 flats across the city, resulting in raised awareness of heat stress among citizens. The 2018 heatwave situation also revealed that emergency procedures are needed for taking care of other vulnerable groups and it raised questions about the division of public health responsibilities during heatwaves between local, regional and national authorities.

Following the Climatools programme, protection against the risk of overheating was included in Botkyrka's regular building inspections. There is a specific focus on cooling solutions for residential homes for the elderly and on pre-school facilities, with regard to both the renovation of existing buildings and the integration of cooling solutions into the design of new buildings. For example, a care centre for the elderly, opened in 2014, is well insulated and equipped with solar energy-driven air conditioning to reduce heat stress for the residents and staff during hot weather.

Mapping of addresses where vulnerable people live. The colours and shapes correspond with different reasons for vulnerability.

Sources: Swedish Portal for Climate Change Adaptation (2016); Klimatanpassningsportalen (2013); Botkyrka Kommun (2014); personal communication from Ingrid Molander, Botkyrka Council (19 September 2018).

5.3.2 Heatwave and cold wave plans

Heatwave action plans usually focus on preventive measures, such as raising public and health sector workers' awareness and response during heatwaves, i.e. issuing heat and health warnings, providing advice to those working with vulnerable groups, managing emergency services and mobilising the resources for managing heat effects. They are usually developed and operationalised by agencies responsible for public health in cooperation with meteorological institutes (e.g. in Austria (Climate-ADAPT, 2017b)). Box 5.4 provides examples of heat action plans focused on vulnerable people across Europe.

Similar types of action plans have been developed for spells of low temperatures. The Lithuanian Health Programme for the period 2014-2025 emphasises the roles that reducing socio-economic inequalities and boosting community solidarity have to play when it comes to mitigating the impact of environment-related injuries (mainly in relation to cold weather). In England, the Cold Weather Plan (PHE, 2018) outlines methods for identifying those who are vulnerable to cold temperatures and, alongside winter preparedness, alert systems and working with service providers, it emphasises engaging the voluntary and community sectors. The former Yugoslav Republic of Macedonia's cold wave action plan is designed to inform health and social care professionals and institutions responsible for protecting people placed at risk by cold weather, including elderly people, infants and pre-school children, as well as people with certain diseases and lower socio-economic status (WHO Europe, 2013a). It is worth noting that while national plans relating to extreme temperatures provide a framework for short-term emergency responses, they cannot replace longer term preventative strategies in managing extreme temperature-related risks for vulnerable groups (Abeling, 2015). Examples of such strategies are outlined in the next sections.

Box 5.4 Examples of heat action plans across Europe

The French Plan Canicule, developed in the aftermath of the disastrous heatwave of 2003, includes a weather alert service, a registry of people at risk and response guidelines for hospitals and voluntary aid workers. City councils nationwide were urged to carry out a census of older people to create a list of 'vulnerable persons' requiring immediate assistance in extreme climatic conditions. The Ministry of Health has also allocated over EUR 20 million to install air conditioning in retirement homes (Bosch, 2004), as all retirement homes need to have at least one air conditioned room with a temperature less than 25 °C on each floor during periods of extreme heat (IEA, 2018). In Lithuania, the Heat Health Action Plan aims to protect the population's health from negative heat impacts, with particular emphasis on the most vulnerable groups, through awareness-raising and preventive measures. In the event of a heatwave in Switzerland, the Federal Office for Public Health provides information on protection measures to vulnerable groups and to people working in the health care system. Similarly, in Sweden, the Public Health Agency's 2017 project Strengthening the ability to cope with adverse health effects of heatwaves aimed to raise awareness of the risk of high temperatures among the elderly and other recipients of care. It also provided guidance on developing heatwave action plans for the local authorities and care providers. In addition, the Swedish County Administrative Boards, in 2011, developed a scenario for heatwaves to be used in risk and vulnerability analyses that are compulsory for municipalities, explicitly taking into account vulnerable groups. The Portuguese heatwave contingency plan also establishes various training and communication activities aimed at vulnerable populations (Climate-ADAPT, 2015).

Most of the heatwave action plans focus on the elderly, children and those in poor health. The city of Kassel, Germany, offers the Heat hotline parasol, a free of charge hotline that elderly citizens can register for to receive heat-warnings from the German weather service. The registration process includes an individual risk assessment, so that appropriate responses can be suggested (Climate-ADAPT, 2017a). In Italy, heatwave plans consider the needs of various groups identified as being vulnerable to heatwaves: the elderly; people with particular physical or mental health problems; pregnant women; people with reduced mobility or dependant on medicines; lower socio-economic status groups; socially isolated people; and those performing physical activities outdoors. Similarly, the Smart Sun Educational Programme in Tatabánya, Hungary, alongside the focus on vulnerable groups, also raises awareness of workers' rights in hot weather, especially if their work includes outdoor activities (Climate-ADAPT, 2014). The German Federal Ministry for the Environment, in its recommendations for drawing up heat action plans, highlights the need for particular care for various vulnerable groups, including people who are isolated, severely overweight or suffering from febrile illnesses, in addition to those mentioned above (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2017).

Sources: References in text and information provided by EEA member countries and the cited Climate-ADAPT case studies.

5.3.3 *Climate change adaptation planning*

Preparing for future changes in climate, at different spatial scales from national to local, is highly relevant to ensuring the protection of vulnerable groups from future high temperatures when taking into account the projections of an increased risk of heatwaves across Europe (EEA, 2017). While social issues have only relatively recently been addressed in adaptation planning (ETC/CCA, 2018), some of the national adaptation strategies (NASs) explicitly refer to various vulnerable groups that may be affected by climate-related hazards in the future. For example, the German NAS is based on a national vulnerability analysis, which explicitly considers the sensitivity of different groups (e.g. according to age structure) and regions alongside their exposure to current and future climate hazards. The Greek NAS includes an action to reduce the health-related risks of climate change on vulnerable groups such as the elderly or people on low incomes. In particular, it advocates mapping population groups most vulnerable to climate change-induced health risks and strengthening existing policies providing shelter to the homeless or those on low incomes during extreme weather events (e.g. operation of cooling or warming centres). The draft of Latvia's Adaptation Strategy 2030 includes a separate objective addressing vulnerable groups (e.g. children, elderly people, those with disabilities, people on low incomes), to be addressed by specific adaptation measures. The Slovak NAS acknowledges that climate impacts can further deepen social inequalities, including poverty and low quality of life, and that the highest priority is given to the adaptation measures that have direct or indirect positive impact on human health and quality of life. An overview of the health considerations in national adaptation planning policies in the EU is provided in a WHO Europe (2018b) report.

Local authorities play a particularly important role in climate change adaptation planning focused on vulnerable people, as they tend to provide social care and health services to the latter. However, social impacts of climate change remain a knowledge gap for urban practitioners (Romanovska et al., 2016). The absence of a common framework across Europe for assessing and addressing social vulnerability to climate change is an obstacle to incorporating social issues in adaptation plans (ETC/CCA, 2018). In some countries, such as in Poland, guidance for cities on developing adaptation action plans, with consideration of social issues, is provided by the national government (Box 5.5).

Box 5.5 Polish Ministry of the Environment supporting the development of socially-aware urban climate change adaptation plans

The project Development of urban adaptation plans for cities with more than 100 000 inhabitants in Poland (44MPA) ([a]) involves Poland's 44 largest cities. It aims to adapt these cities to observed and projected climate changes. The project is a unique initiative in the European context in which the national Ministry of the Environment supports local authorities, coordinating activities aimed at developing adaptation action plans of so many municipalities simultaneously.

The Polish Ministry of the Environment developed a handbook for urban practitioners and consultants supporting participating cities in developing adaptation action plans, which outlines the scope of adaptation planning and provides methodology for implementing the project. The handbook, among others, offers guidance on considering groups that are particularly sensitive to climate change in adaptation planning. As a result, 42 out of the 44 cities participating in the project identified public health among the sectors most sensitive to climate change. The presence and spatial distribution of elderly people, children, those with disabilities, those who are chronically ill and the homeless have been considered in the vulnerability assessments for these 42 cities. In addition, the availability and distribution of social infrastructure and social services for the elderly and the homeless, for example, was assessed. While those on low incomes, those with low levels of education and the unemployed are considered in the assessment of the cities' adaptive capacities, no specific adaptation actions are targeting these groups in the plans.

The following adaptation options that specifically address vulnerable groups are being compiled for the 42 cities: actions improving the functioning of municipal services and social infrastructure; extreme weather warning systems for residents; measures aimed at strengthening public awareness of risks associated with climatic events; and initiatives encouraging community self-help. Furthermore, the multi-criteria assessment of all adaptation options includes checking whether the solution has a negative impact on weaker socio-demographic groups. The adaptation plans will be completed by the end of 2018.

Source: Personal communication from Marcin Grądzki and Piotr Czarnecki, Ministry of the Environment, Poland (22 October 2018).
([a]) http://44mpa.pl/?lang=en (accessed 29 November 2018).

5.3.4 Heat-proof housing and neighbourhoods

Identifying vulnerable locations can help to target the responses that reduce exposure to high temperatures by addressing the quality of the physical environment. In particular, greening cities can help to reduce temperatures in urban settings while providing valuable co-benefits for health and social cohesion (ten Brink et al., 2016). For example, in Trnava, Slovakia, identifying the area where people most susceptible to harm from high temperatures live has led to a neglected open space being re-designed as a park and consequently providing respite from high temperatures for those living nearby (Climate-ADAPT, 2018). In Berlin, the socio-economic characteristics of the population are used as criteria in selecting areas for greening projects, with areas of lower socio-economic status being given priority for creating new green areas and improving existing spaces, including a system of subsidies ([29]).

In Hammersmith and Fulham, London, provision of new green spaces and water features in social housing estates to reduce temperatures was combined with in-depth community engagement and awareness-raising of climate change (Climate-ADAPT, 2016). The engagement of local residents in planning and implementing changes to the neighbourhood is crucial, as emphasised by the KiezKlima project in Berlin (Box 5.6).

Despite the overheating of housing being one of the main drivers of excess deaths during heatwaves (see Section 2.4.3), there are not many examples of practical action addressing this issue. Older tower blocks are particularly prone to overheating because of poor insulation. They are a typical form of social housing in the United Kingdom and France and form a large part of the housing stock in the vast post-socialist estates in central and eastern Europe, therefore they frequently provide housing to lower income groups. In 2010, the London Borough of Barking and Dagenham carried out a renovation of two tower blocks, which included anti-overheating measures (reflective blinds in windows, reflective coating on walls, roof insulation, mechanical extractor fans). As a result, half of the residents surveyed after the maintenance work noticed that internal temperatures were lower (London Climate Change Partnership, 2013). In the city of Dresden, Germany, the district Dresden-Gorbitz, containing 1980s prefabricated-slab apartment blocks, is the subject of an ongoing HeatResilientCity project ([30]). Both behaviour adaptation and physical measures of building conversion will be tested in this 'living lab', in close collaboration with the residents.

Box 5.6 Engaging local residents in adapting their neighbourhood to high temperatures in Berlin, Germany

The project KiezKlima (2014-2017, funded through the national adaptation funding mechanism of the Federal Environment Ministry and led by L.I.S.T. GmbH) aimed at engaging local residents in a Berlin neighbourhood in inclusive and innovative adaptation planning at the local scale. Local residents were involved in the development and implementation of a range of low-cost adaptation measures to cope with heat stress, which explicitly focused on socially vulnerable groups. Measures included, for example, the construction of shading structures in the local kindergarten, the installation of a public drinking water fountain and backyard greening for local multi-generation housing. The strong participatory approach of the project was targeted at at-risk groups (e.g. the elderly and chronically ill, infants) with little adaptive capacity. For its innovative approach, the project was awarded the national adaptation award 'Blauer Kompass' by the German Environment Agency in 2016.

Source: http://www.kiezklima.de (accessed 29 November 2018).

5.3.5 Community self-help initiatives

Social isolation has been identified as one of the main factors contributing to the deaths of vulnerable individuals during heatwaves (Poumadère et al., 2005), and therefore actions aimed at reducing its occurrence can save lives. For example, the Paris Adaptation Plan calls for not only pharmacists and medical practitioners but also shopkeepers ([31]) to identify people who are particularly vulnerable to high temperatures due to poor health, social isolation or homelessness, so that they can be included in the local registers of vulnerable people, in case they are missing from the social care or public health lists (ETC/CCA, 2018). In Bologna, Italy, volunteers and non-governmental organisations provide physical assistance to vulnerable individuals during heatwaves. The services provided include a

([29]) https://oppla.eu/node/18090 (accessed 29 November 2018).
([30]) http://heatresilientcity.de (accessed 29 November 2018).
([31]) Shopkeepers in Paris have been involved in a bottom-up initiative providing services (a hot meal, a glass of water, restroom access, mobile phone charge, etc.) to homeless people (City Lab, 2018).

toll-free call centre providing information for citizens, checking up on people at risk and keeping them company, bringing them food and medicines and accompanying them to cooling centres or hospitals (Iperbole, 2017). Similar initiatives exist to support vulnerable people during cold spells. In Cheshire, United Kingdom, the 'Snow Angels' are volunteers recruited from the local area, who visit socially isolated people, mainly the elderly, and undertake practical activities, such as clearing and gritting paths when there is snow and ice. Included as part of the service are weekly telephone calls to the vulnerable people who have signed up (Climate Just, n.d.).

5.4 Cross-cutting issues

5.4.1 Addressing multiple hazards

The evidence review in Chapter 2 indicates that the same vulnerable groups tend to be the most negatively affected by different hazards. At the same time, common locations (in cities in particular) tend to be affected by air pollution, noise and high temperatures, in addition to suffering from socio-economic problems. Identification of areas affected by the accumulation of environmental and social problems enables the prioritisation of the most vulnerable and exposed communities in targeting responses. For example, the Berlin Environmental Atlas (Senate Department for Urban Development and Housing, n.d.) recognises environmental justice as one of the key topics and presents the relevant information spatially. Information is available on the distribution of air pollution, noise, bio-climate and availability of green spaces — these maps can also be combined to identify the areas with the highest environmental health hazard load. The Berlin Environmental Atlas also enables mapping of the social status of different areas (indicators including unemployment, child poverty and receipt of certain types of benefits) and putting these maps of environmental health hazard load and social deprivation together to identify where social and environmental problems coincide and target actions.

The previous chapters have indicated that issues such as poor-quality housing, prevailing transport type and traffic intensity or inadequate spatial planning may lead to disproportionate exposure of vulnerable groups to various environmental health hazards. Therefore, measures focused on these aspects are likely to address exposure to multiple hazards as well as reduce vulnerability (Table 5.1). Promotion of active travel and public transport can reduce car use and, consequently, air and noise pollution near roads. Higher levels of physical activity associated with cycling and walking can improve general health and thus reduce one cause of vulnerability. The health benefits of active mobility (walking and cycling) are enhanced if changes in transport are accompanied by increases in green space, which has been proven to reduce temperatures, remove some of the air pollution and provide a noise barrier, in addition to improving mental well-being (ten Brink et al., 2016). Changes to the ways in which European cities are laid out, focusing development

Table 5.1 Types of measures helping to address exposure to multiple hazards and social vulnerability

Measure type	Reduced exposure				Reduced vulnerability
	Air pollution	Noise	Heat	Cold	
Active mobility and public transport	✓	✓			✓
Urban planning and design focusing on green infrastructure and transit-oriented development	✓	✓	✓		✓
Housing with adequate thermal isolation, noise reduction and ventilation		✓	✓	✓	✓
Awareness-raising and encouraging participation	✓	✓	✓	✓	✓

around transport nodes, can further reduce car use and the need for commuting while also reducing social segregation (WHO Europe, 2010).

Europeans spend 80 % of their time in buildings and, in the case of vulnerable groups, the proportion of time spent indoors in one location can be even higher. It is therefore crucial to ensure low levels of noise and air pollution around nurseries and kindergartens, schools, hospitals and care homes and to ensure that the buildings where vulnerable groups spend their time provide comfortable temperatures and acoustic isolation. Reduced exposure of people to at least some of the environmental health hazards while in buildings can increase their capacity to cope with other hazards.

Awareness-raising of the impacts of environmental health hazards is particularly important among the lower socio-economic groups, which may have less knowledge of the risks and less leverage when trying to persuade local politicians to improve their environment or to oppose actions that would reduce environmental quality. As a result, more deprived communities tend to have less influence on the decision-making processes (Derounian, 2016) that may lead to the distribution of environmental health hazards, such as planning decisions on transport and the location of industrial installations. Individuals from lower socio-economic groups are more likely to be unaware of planned changes, have a lack knowledge of procedures, be disinclined to participate in legal processes and be unsuccessful when involved (Aalbers et al., 2014). Conversely, evidence from France suggests that individuals submitting noise complaints to authorities generally come from a fairly high socio-cultural background, know their rights and expect to be listened to (Barnes et al., 2018). To encourage participation of vulnerable groups, in Poland, the governmental programme Clean Air ([32]) encompasses a series of meetings with local communities explaining how to obtain financial support to improve the energy efficiency of houses. In addition, local social care workers have been trained to provide this information to their clients, thus extending the reach to vulnerable groups.

5.4.2 Managing trade-offs

While finding synergies is of key importance, specific designs of measures should take into account some potential conflicts and trade-offs in their response to different hazards that may emerge. For example, in housing improvements, a balance is required between providing insulation and good ventilation of buildings, as reduced air exchange may lead to the deterioration of air quality, resulting in health risks (WHO Europe, 2012). The traditional mitigation measures for noise, such as double glazing, are not effective in the summer when windows need to be open for ventilation. Also, one might expect that materials and structures providing better heat insulation reduce noise problems as well; however, materials or technical solutions that improve the thermal resistance of a building partition often reduce its acoustic performance (Nurzyński, 2015). An integrated approach requires know-how in reducing both noise and temperatures. In the United Kingdom, the Association of Noise Consultants recommends an approach to acoustic assessments for new residential developments that takes due regard of the interdependence of provisions for acoustics, ventilation and overheating (ANC, 2018).

Another example is weighing up the health benefits of air conditioning for vulnerable groups during hot spells against energy use and associated greenhouse gas emissions, as well as the possible negative health impacts of air conditioning. Air conditioning in individual households may not be sustainable in the long run; a compromise is offered in instances where air conditioning is provided in public buildings in cities, which grants access for many people (e.g. in Bologna or Paris, see Section 5.3), or in buildings catering for vulnerable groups (e.g. care homes for the elderly) (see Box 5.3). Alternative solutions to traditional air conditioning that are beginning to emerge include district cooling systems or solar-powered cooling (IEA, 2018). Similarly, the use of air purifiers may improve the air quality inside buildings, but they indirectly contribute to higher levels of pollution through energy use.

Addressing vulnerable groups' exposure to the cold should also be undertaken carefully, in order to not exacerbate air pollution through inadequate heating. This may be the case when low-cost energy sources are being used, including poor-quality coal, waste, wood and residual agricultural biomass (WHO Europe, 2012). The example of Dublin (Box 5.2) shows how tackling air pollution by banning low-quality fuel may have an impact on people's ability to keep their houses warm.

([32]) https://www.mos.gov.pl/czyste-powietrze (accessed 29 November 2018).

6 Looking ahead

Key messages

- The spatial and societal inequalities in vulnerability and exposure to the environmental health hazards considered in this report are likely to persist because of the ongoing changes in socio-demographic and environmental quality in Europe.
- Enhancing the coherence between EU policies in terms of human health, climate change and air pollution agendas in the EU policy framework may help to address the inequalities in environmental impacts.
- At the local level, multiple policy areas from welfare policies to urban design can help to reduce the vulnerability and exposure of the population.
- Improving spatial coverage and higher resolution of socio-economic data, establishing methodological approaches and addressing the gaps in knowledge on the distributional impacts of noise and the combined effects of multiple environmental health hazards would enhance future assessments of the links between societal inequalities and environmental quality.

6.1 Future outlook on social vulnerability and environmental health hazards

Both society and the environmental quality in Europe are changing. Increasing life expectancy combined with low birth rates means that the European population is ageing. For western Europe, the percentage of people aged 65 or older is currently around 18 % and this proportion is projected to roughly double by 2100. For central and eastern Europe, the proportion of older people is projected to be between 29 % and 50 % by 2100. The urban population is also expected to increase continuously, exceeding 90 % in western Europe under some socio-economic scenarios, with more variable projections for central and eastern Europe. The net migration into Europe is also projected to increase, with the highest levels in countries such as Italy and Germany. While this is not enough to offset the ageing trends, it will contribute to the size and diversity of many European cities (EEA, 2017).

The projected rate of economic growth in Europe varies depending on the scenarios, but most of them tend to indicate higher growth for western Europe than for the east. These projected trends mean that the future 'coping capacity' of Europe, as assessed in the context of the changing climate for a variety of socio-economic criteria, will continue to be higher in north-western Europe than in the south-east (EEA, 2017). In addition, there are also risks of another financial crisis, which may threaten the progress made in increasing equality across Europe in recent years (EC, 2017c) and put people living in countries with less robust economies at further material disadvantage.

Europe is moving towards the air pollutant emission and air pollutant concentration objectives and targets framed in EU legislation. The latest trends in concentrations of PM (both $PM_{2.5}$ and PM_{10}) and NO_2 show a general decrease. However, the situation for O_3 is mixed, depending on the metrics (for instance, the annual mean increased at traffic stations, even though all metrics showed a declining trend at rural stations) (EEA, 2016). Even if most trends indicate a reduction in concentrations at most of the stations, there are persistent exceedances of the EU standards, especially for PM, NO_2 and O_3. Importantly, achieving the WHO air quality guidelines (see Table 3.2) in numerous locations is even further away for many air pollutants.

As air pollutant concentrations fall, the premature mortality associated with air pollution also decreases; for example, premature mortality attributed to exposure to $PM_{2.5}$ in Europe fell by about 60 % between 1990 and 2015 (ETC/ACM, 2018b). Beyond 2020, and without further measures to abate emissions, the impacts of air pollution on health will continue to decrease, albeit at a considerably slower rate (Maas and Grennfelt, 2016).

The full implementation of EU legislation on air quality and emissions by 2030 would almost eliminate the exceedance of the annual EU limit of NO_2 values (which are the same as the WHO annual guidelines) and an overwhelming majority of countries would record $PM_{2.5}$ concentrations below the annual level included in the WHO guidelines. Nonetheless, some regional inequalities are likely to persist. The decrease in precursor emissions of ambient $PM_{2.5}$ in the emission reduction requirements under the 2016 NEC Directive scenario results in the loss in average statistical life expectancy, attributable to exposure to $PM_{2.5}$, being reduced from 9 months in 2005 to 4.1 months in 2030. However, in the Benelux region, northern Italy, Poland and Czechia, between 5 and 6 months would be lost (IIASA, 2018). Furthermore, if the current patchy implementation of EU air quality and emissions legislation (ECA, 2018) continues, so will the higher and varied levels of air pollution, and thus actions aimed at protecting particularly vulnerable areas and groups would be required.

With regard to noise, the projections of rapid urban growth in Europe and increased demand for road, rail and air transport mean an expected increase in noise exposure and its adverse effects on health (Jarosińska et al., 2018). Noise projections from various transport modes are very much associated with technological improvements in terms of engines, tyres/wheels and surfaces. For example, the total number of people exposed to aircraft noise may increase, stabilise or potentially decrease by 2035, depending on future technological improvements and air traffic intensity (EASA et al., 2016). Similarly, various measures are being developed in noise abatement technologies for road and railway traffic. The increasing number of wind turbines in Europe has resulted in noise annoyance in some locations, despite being an important component of renewable energy supply (Jarosińska et al., 2018).

The climate is changing and, among other issues, it will bring about higher temperatures, and more frequent and more extreme heatwaves (EEA, 2017). Urban areas in particular, where the majority of Europeans live, will be affected in the future. Towards the end of the 21st century, the number of heatwave days in urban areas is projected to increase by a factor of 10 (Hooyberghs et al., 2015). Return periods of 1 in 20 years for heatwave events are projected to decrease to 7 years under the scenario of a 1.5 °C increase in global temperatures and to 5 years under the 2 °C scenario (Jacob et al., 2018). This increase in heat extremes will lead to a marked increase in heat-attributable deaths — especially considering the ageing European population — unless adaptation measures are taken. The third Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis project (PESETA III) estimates that under the high-end emission scenario ([33]) heat-related deaths in Europe would increase by 132 000 per year by the 2080s (a factor of 50 compared to the present), with the highest increase in central and southern Europe (Ciscar et al., 2018). The proportion of the European population unable to keep their homes comfortably cool during summer is, at present, higher than the proportion unable to keep their homes warm during winter, demonstrating that summer temperatures are already a rising problem (WHO Europe, 2012) and are likely to become more so in the future. However, despite the general warming trends, the cold has remained an important risk factor for mortality in recent years (Hajat and Gasparrini, 2016). Even considering the projected milder winters, moderate cold is expected to continue as the greatest temperature-related health risk throughout this century (Arbuthnott et al., 2016; Vardoulakis et al., 2014).

The changing climate is also likely to have implications for air pollution levels in Europe. In areas with high levels of NO_x, elevated surface temperatures and humidity may increase surface O_3. This is a particular threat for southern Europe. Future changes in

([33]) Under this scenario, projections of Global Warming Level (defined as the temperature global mean temperature increase compared to the pre-industrial period) exceed 3 °C warming around 2070 and continue rising thereafter (Ciscar et al., 2018).

PM concentrations due to climate change are much less certain, but increases may also occur in hotter and more humid conditions with lower precipitation (Doherty et al., 2017).

These future projections indicate the urgent need for developing equitable and sustainable solutions to the unequal impacts of environmental health hazards on European society, related to both the differentiated vulnerability and the uneven exposure levels now and in the future. This need is particularly pressing in urban areas, where the majority of Europeans live.

6.2 Towards equity-oriented policy and practice

Focusing on protecting vulnerable groups in policy and action, and on achieving equitable outcomes of policies is consistent with the 7th EAP (EC, 2013f), as well as with the underlying principles of the EU encompassed in the Lisbon Treaty (EU, 2007). However, the social distribution of environmental risks is not coherently tackled under environmental policies in the EU. This section discusses the opportunities for addressing socio-environmental inequalities through policy and practice, at scales ranging from European to local.

6.2.1 Opportunities in EU policy

According to the 7th EAP, in order to ensure a healthy environment for all, local measures should be complemented with appropriate policy at both national and EU level (EC, 2013f, Article 45). However, an integrated and combined approach to air pollution, public health and social inequality is still in its early stages in Europe, with air quality policies rarely incorporating specific socio-economic dimensions (Aalbers et al., 2014). In addition, in relation to adapting to the risk of high temperatures, social justice issues have only recently started to be considered in NASs (Boeckmann and Zeeb, 2014). While social vulnerability is already recognised in a number of key environmental policies in Europe, some additional opportunities for integrating social and environmental agendas could be considered, for example:

- **Enhancing coherence between health, climate change and air pollution policies.** The links among these three policy areas are recognised by WHO, which called the Paris Agreement 'potentially the most important public health agreement of the century', on account of the health gains linked to improved air quality that can be achieved by reducing the burning of fossil fuels (UNFCCC, 2018). This could also help to address air pollution problems due to biomass use, which is becoming a more popular renewable fuel as a result of climate change policies. Many EU policies have an impact on air quality, but some of them still do not sufficiently reflect the importance of improving air quality (ECA, 2018). Therefore, air quality policies may be more effective when they are integrated with other policies, for example the EU-climate and energy policy (Partnership for Air Quality, 2017).

- **Bringing together the different action plans under the Urban Agenda for the EU.** Developing and implementing the action plans of the partnerships, focused on air quality, climate change adaptation and urban poverty, could be done in a more integrated way, i.e. by recognising the links between these issues, in order to benefit the vulnerable communities affected by environmental hazards. So far, the need for such links has not been highlighted in the current action plans on urban poverty (Urban Poverty Partnership, 2018), air quality (Partnership for Air Quality, 2017) or the Climate Adaptation Partnership draft action plan (Climate Adaptation Partnership, 2018).

- **Addressing socio-environmental inequalities through EU cohesion funds**, as environmental inequalities seem to follow the pattern of socio-demographic inequalities across Europe. This could be achieved through developing specific funding aimed at improving environmental quality in disadvantaged urban neighbourhoods, for example. The action plan of the Urban Poverty Partnership under the EU Urban Agenda states that EU funds are not sufficiently concentrated on specific areas to effectively address urban poverty in deprived neighbourhoods (Urban Poverty Partnership, 2018). The plan proposes that the EU cohesion policy post 2020 secures specific funds for deprived neighbourhoods, which also offers an opportunity for addressing the environmental quality (Urban Poverty Partnership, 2018).

- **Building on existing environmental policies that draw attention to vulnerable groups.** The

Partnership on Air Quality (2017) under the Urban Agenda for the EU calls for the development of a code of good practice for air quality action plans, which already make allowances for addressing vulnerable groups. Such a code of good practice could be an efficient way of drawing attention to vulnerable groups in air quality action plans. In the same way, noise policies could take into consideration the recommendations made by the recent WHO Environmental noise guidelines for the European region (WHO Europe, 2018a) on the exposure level at which cognitive effects on children undoubtedly begin.

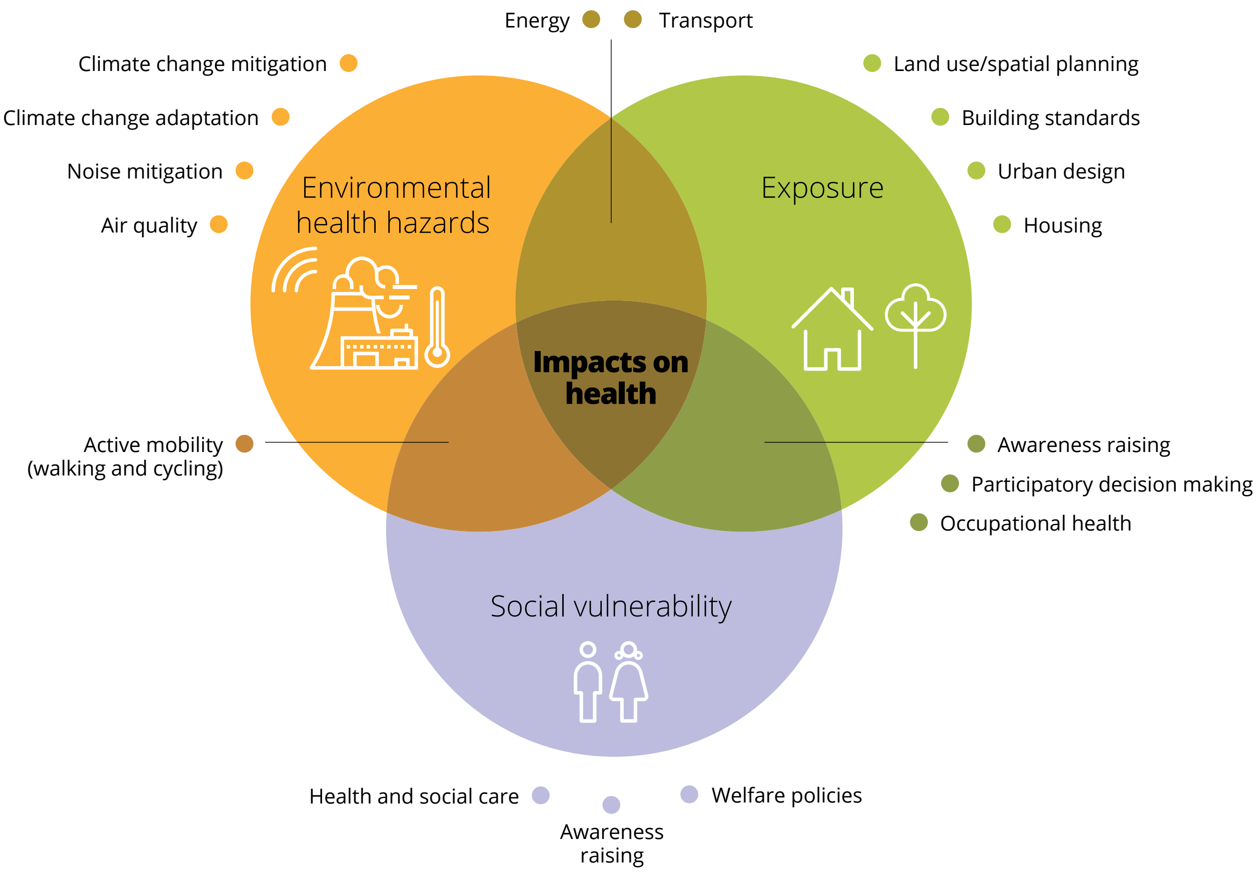
- **Facilitating equitable responses to environmental health hazards at a local level through European Commission initiatives.** The European Commission initiatives have a role to play in facilitating equitable responses to environmental hazards at the local level. For example, within the EU adaptation strategy (EC, 2013c), a key action is the support for urban adaptation from the Covenant of Mayors for Climate and Energy. This EU-funded initiative provides support to local governments on developing adaptation action plans, including responses to extreme temperatures. The evaluation of the EU adaptation strategy calls for an even stronger focus on urban adaptation and consideration of vulnerable groups in adaptation planning and implementation (EC, 2018b). This could be possibly tackled by the Covenant of Mayors preparing specific guidance for its signatories on treatment of vulnerable groups. The initiative may also lead to improvements in air quality through its contribution to reducing greenhouse gas emissions and promoting transition to a low-carbon economy at local level (EEA, forthcoming).

- **Measuring the progress towards sustainability with integrative indicators.** The data collected for quality of life indicators (Eurostat, 2015a) allow some comparisons of various dimensions, not only among countries but also among different age and income groups, to show how environmental characteristics affect the well-being of various social groups. A similar approach could be extended to the 'multi-purpose' indicators measuring progress towards the SDGs. Developing indicators combining environmental and social aspects could allow changes in socio-environmental inequalities to be captured. Indicators such as the 'percentage of vulnerable households unable to keep their homes at comfortable temperatures', (Eurostat, 2016) or 'asthma-symptom days in children' (EC, 2013a) could be used across several environmental and social goals.

6.2.2 Addressing drivers of exposure and vulnerability at national and sub-national levels

In order to reduce overall levels of air pollution and noise, Member States need to be improve their level of implementation of the EU directives (see for example ECA (2018)). While the environmental health hazards persist, their impacts on the population depend not only on the presence and intensity of environmental health hazards in a given area, but also on the exposure and vulnerability of people caused by intertwined social, economic and environmental issues (see Figure 2.1 in Chapter 2). Therefore, paying attention to reducing exposure to environmental health hazards or reducing underlying vulnerability in various policy areas may help to ensure the overall reduction of impacts (Figure 6.1). There is evidence, for example, that increased spending on health could reduce excess winter mortality in southern and western Europe (Healy, 2003). The Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy (EC, 2015b) stresses that energy poverty should be tackled by a combination of measures, mainly those in the social field, implemented by national, regional or local authorities (see Box 4.1). Section 5.4 of this report provides examples of how spatial planning, transport or housing policies, or engaging local communities, can help to address multiple hazards and vulnerability. Thus, a multi-pronged approach aimed at improving both social equality and the environment more broadly could be one way of effectively reducing impacts on vulnerable groups. Furthermore, the EEA (forthcoming) analysis of air quality management in European cities calls for improved coordination of actions concerned with air, health, energy, transport and urban planning.

Figure 6.1 **Examples of policy areas relevant to reducing environmental health hazards, exposure and social vulnerability**



6.3 Knowledge gaps

6.3.1 Data availability

One obstacle in performing this assessment was the availability of socio-demographic data of appropriate geographical coverage, granularity and timeliness. The smallest spatial units for which data were available across Europe were NUTS 3 regions or Urban Audit cities, and this was for only a limited range of indicators (see Table 3.1). In many cases the data coverage was not complete coverage even for the EU-28 Member States, with many gaps present for the other EEA member countries. The identified data needs are as follows:

- Complete European coverage of indicators directly linked to social vulnerability, e.g. those concerning poor health, social housing or reliance on welfare. The need for solid statistical data on urban poverty at the NUTS 3 level, allowing an overview of the situation of children at risk of poverty and social exclusion, homelessness and the Roma community in the EU, has also been highlighted by the Urban Poverty Partnership under the Urban Agenda for the EU (Urban Poverty Partnership, 2018).

- The single values of socio-demographic indicators for NUTS 3 regions or Urban Audit cities do not allow for the assessment of within-region inequalities in vulnerability and exposure. Consequently, improved access to socio-demographic data at higher resolutions is needed to carry out assessments against noise or air quality data sets, which in many locations are available at fine scales.

- As highlighted in Section 6.2.1, integrating social and environmental issues in indicators measuring progress towards sustainable development could be beneficial and, therefore, developing data sets for these indicators would be of use.

While the data on air quality and temperatures have an adequate spatial coverage across Europe, the noise data set was limited to road noise for 35 % of the total urban areas in Europe. This is primarily due to the implementation of reporting under the END. Data on other sources of noise are available within the END; however, the road noise data set is the most complete. There remains a clear need to improve Member States' implementation of the END, particularly regarding the completeness, comparability and timeliness of reporting (EEA, 2015).

6.3.2 Methodological approaches

There is no standardised or commonly accepted way of assessing social vulnerability to environmental health hazards. A review of guidance documents on urban climate adaptation planning reveals that the type and range of indicators differ considerably (ETC/CCA, 2018). Depending on the indicators or proxies used, the results of assessment, such as the one carried out in this report, can differ.

Similarly, numerous climatic indicators can be used to express the extreme temperatures that may be dangerous to human health; there is a variety of ways to define heatwaves, cold waves and HDDs or CDDs. In the case of noise, the threshold of 55 dB was used in this report to identify the proportion of the population exposed to noise, whereas using a higher threshold would help to identify areas with a more acute problem of environmental noise. Therefore, the choice of indicators in an assessment such as this one substantially affects the results.

This assessment concerned different spatial scales, through analyses carried out for two levels of NUTS regions and the review of evidence available for individual locations. Nonetheless, there remains a need for further assessment of exposure to and the impacts of environmental health hazards on people at various scales, from individual- and cohort-based to population studies. Such investigations would help to avoid the problem of ecological fallacy, whereby observed risks for small areas may not apply to all individuals in that area (Halonen et al., 2016; see also Box 3.4), and would therefore allow for greater certainty in assessing exposure and vulnerability differences across European society.

6.3.3 Knowledge development

There is extensive evidence on the health effects of exposure to air pollution and extreme temperatures. However, in relation to noise, WHO recognises that there is a lack of literature on the effects of noise on vulnerable people and that there is a need for future epidemiological noise research to focus on vulnerable groups (WHO and JRC, 2011). Although acceptable noise thresholds are difficult to establish for most vulnerable groups as a result of the limited number of studies available, the WHO Europe (2018a) provide a value at which the risk increase of impaired reading and oral comprehension in children becomes apparent.

In addition, gaps are still evident in the body of research helping to fully understand the interlinkages between air pollution, noise and extreme temperatures and the extent to which any of these multiple hazards are additive or multiplicative in their effects (Barnes et al., 2018). Furthermore, environmental equity research and related publications are not evenly distributed and available for all European countries; a more comprehensive coverage of studies across Europe, particularly analysing the within-country inequalities, would enhance our knowledge on unequal impacts and unequal exposure of different socio-demographic groups.

This report did not consider ethnic minorities, migrants, tenants and other groups that the literature recognises as more affected in certain circumstances by environmental health hazards (ETC/CCA, 2018). Synthesising knowledge on the exposure of these groups to environmental health hazards and the impacts they experience as a result would allow the development of policies and practical responses aimed at these groups. In addition, this report has a strong urban angle, on account of the overall urban focus in the literature related to air pollution, noise and heat effects on people, and yet, in many countries, older populations or those at risk of poverty may mainly live in rural areas (Eurostat, 2015a). There is a need for more knowledge on the interactions between social vulnerability and exposure to environmental health hazards in rural areas.

Furthermore, little is known about the effectiveness of policy measures and whether they improve environmental equity among vulnerable groups. There is a need to evaluate existing policies in the environmental area to establish the extent to which they promote social justice or whether they adversely affect the weaker socio-demographic groups.

6.3.4 Knowledge dissemination

There is a need to enhance the sharing of knowledge on effective responses to inequalities in exposure to environmental health hazards. This is particularly valid in the case of air pollution and noise, for which fewer examples of actions targeted specifically at vulnerable groups have been identified than for extreme temperatures. This is partly related to the acute character of risks associated with extreme temperatures and the more immediate effects on vulnerable groups than the longer-term more chronic character of the effects of air pollution and noise exposure.

The exchange of experiences among cities on effective air quality management strategies could be facilitated by a dedicated platform (EEA, forthcoming), also taking into account the actions aimed at vulnerable groups. Sharing experiences of developing air quality action plans (which offer the potential to plan for vulnerable groups) and knowledge on best practices is recommended by the Partnership on Air Quality (2017) under the EU Urban Agenda. Existing knowledge-sharing platforms, such as the Directorate-General for Health and Food Safety's Public Health Best Practices Portal ([34]), could offer a home for the exchange of experiences.

([34]) https://webgate.ec.europa.eu/dyna/bp-portal/index.cfm (accessed 29 November 2018).

List of abbreviations

List of abbreviations

7th EAP	Seventh Environment Action Programme
AAQ	Ambient Air Quality (Directive(s))
CDDs	Cooling degree days
CRED	Centre for Research on the Epidemiology of Disasters
DALY	Disability-adjusted life years
dB	Decibels
EC	European Commission
ECA	European Court of Auditors
EEA	European Environment Agency
EIA	Environmental Impact Assessment (Directive)
Eionet	European Information and Observation Network
END	Environmental Noise Directive
ESF	European Social Fund
ESPON	European Spatial Planning Observation Network
ETC/ACM	European Topic Centre on Air Pollution and Climate Change Mitigation
ETC/CCA	European Topic Centre on Climate Change Mitigation Impact, Vulnerability and Adaptation
EU	European Union
EU-SILC	European Union statistics on income and living conditions
GDP	Gross domestic product
HDDs	Heating degree days
IARC	International Agency for Research on Cancer
ICLEI	Local Governments for Sustainability
IPCC	Intergovernmental Panel on Climate Change
ISCED	International standard classification of education
L_{den}	Day-evening-night equivalent level of noise
L_{night}	Night equivalent level of noise
NAS	National adaptation strategy
NEC	National Emission Ceilings (Directive)
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
NUTS	Nomenclature of territorial units for statistics (Nomenclature des unités territoriales statistiques)
O_3	Ozone

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OECD	Organisation for Economic Co-operation and Development
PESETA	Projection of economic impacts of climate change in sectors of the European Union based on bottom-up analysis (project)
PHE	Public Health England
PM	Particulate matter
$PM_{2.5}$	Particulate matter with an average aerodynamic diameter of up to 2.5 μm
PM_{10}	Particulate matter with an average aerodynamic diameter of up to 10 μm
ppb	Parts per billion
RCP	Royal College of Physicians
SDG	Sustainable Development Goal
SEA	Strategic Environmental Assessment (Directive)
SEP	Science for Environment Policy
SOMO35	Sum of means over 35 ppb
SD30TN20	The number of days with maximum temperature exceeding 30 °C and minimum temperature above 20 °C per year
SD35	The number of days with maximum temperature exceeding 35 °C per year
TSO	The Stationery Office
UHI	Urban heat island
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations International Children's Emergency Fund
UNISDR	United Nations International Strategy for Disaster Reduction
WHO	World Health Organization
WMO	World Meteorological Organization
YLD	Years lost due to disability
YLL	Years of life lost

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