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Healthy environment, healthy lives: how the environment influences health and well-being in Europe

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Executive summary

Nature provides the basis for the good health and well-being of the European population. Clean air, water and food are essential for sustaining life; natural environments provide space for recreation, relaxation and social interaction; and raw materials feed into our production systems to provide the comforts of contemporary life.

At the same time, environmental pollution is unavoidable. We are exposed to pollution in our homes, in our workplaces, in the outdoor environment and when we eat, play, sleep, drive, walk, swim or run. In 2012, 13 % of all deaths in the EU were attributable to the environment (WHO, 2016a). These deaths are preventable and can be significantly reduced through efforts to improve environmental quality.

The COVID-19 pandemic provides a stark example of the inextricable links between human health and ecosystem health. This novel disease is thought to have emerged in bat populations and subsequently jumped species to infect humans in a seafood and animal market. The emergence of such zoonotic pathogens is linked to environmental degradation and human interactions with animals in the food system. Other factors, such as exposure to air pollution and social status, seem to affect transmission and mortality rates in ways that are not yet fully understood.

The current situation

The state of the environment in Europe is negatively affecting the health and quality of life of European citizens. The World Health Organization (WHO) produces data periodically on the global burden of disease attributable to the environment, with the most recent available data — published in 2016 — indicating that there were 630 000 deaths attributable to the environment in the EU in 2012. The burden of environmental disease is unevenly spread across Europe, with the percentage of deaths attributable to environmental factors ranging from a low of 9 % in Norway and Iceland to 23 % in Albania and 27 % in Bosnia and Herzegovina. Environmental pollution is linked to a range of disease outcomes, including cancer, heart disease, stroke, respiratory disease and neurological disorders. Living with these diseases reduces quality of life, with more than 20 million healthy life-years lost because of disease attributable to poor-quality environments in the 28 Member States of the EU (EU-28) in 2012.

People are exposed to multiple environmental stressors at any one time, which combine and in some cases act synergistically, causing impacts on health. In particular, air pollution and high temperatures are known to act synergistically, leading to increased morbidity and mortality. The urban environment is characterised by the presence of multiple stressors, with people in cities being more exposed to air pollution, noise and chemicals while also having less access to green space than people in rural environments.

- Air pollution is the principal environmental factor driving disease, with around 400 000 premature deaths attributed to ambient air pollution annually in the EU. Poor indoor air quality related to the burning of solid fuels results in nearly 26 000 premature deaths annually across the EEA-39 ([1]). There is early evidence to suggest that long term exposure to air pollution may increase susceptibility to COVID-19, with further research needed.

- Noise is the second most significant environmental risk, with exposure to environmental noise causing 12 000 premature deaths annually and contributing to 48 000 new cases of ischaemic heart disease.

- The health impacts of climate change are complex and include the immediate dangers of extreme weather events, such as heatwaves, extreme cold and floods, as well as changing patterns of vector-borne and water- and food-borne diseases.

([1]) The EEA-39 includes the 33 member countries of the EEA plus six collaborating countries (Albania, Bosnia and Herzegovina, Montenegro, North Macedonia, Serbia and Kosovo (under UN Security Council Resolution 1244/99)).

Heatwaves are the deadliest type of extreme weather across Europe as a whole, with urban areas particularly affected because of the heat island effect. Under current global warming scenarios, additional deaths due to heatwaves could reach over 130 000 per year. Heavy precipitation, floods, rising sea levels and heatwaves as well as long-term climatic shifts present threats to infrastructure, food production and other economic activities. Other knock-on effects of climate change, for example biodiversity loss, will have indirect impacts, such as reduced agricultural productivity and a lower potential for identifying plant-based medicines.

- A wide range of chronic diseases is associated with exposure to hazardous chemicals, with the WHO estimating that 2.7 % of global deaths are attributable to chemical exposure. However, the total burden of chemicals on health in Europe is unknown, since understanding of the exposure of the European population to chemicals is limited. There are also knowledge gaps regarding the effects of exposure to mixtures of chemicals that act synergistically and the effects of long-term exposure to endocrine disruptors.

- Exposure to electromagnetic fields in Europe is both poorly understood and anticipated to increase. While there are well-defined acute health effects of exposure to certain electromagnetic fields, including symptoms such as nerve and sensory organ stimulation and the heating of tissues, there is little evidence regarding the health impacts of long-term exposure for the general population.

- Water pollution can have an impact on health via contaminated drinking water extracted from groundwater or surface water or contact with contaminated bathing waters, as well as through indirect exposure through the consumption of fish containing bioaccumulative pollutants, such as mercury. The quality of bathing water across Europe is consistently high, driven by the successful implementation of EU policies. European bathing water provides an excellent opportunity for people to relax and exercise in clean natural environments.

- Drinking water quality is also consistently high across the EU, according to the parameters currently monitored. The possible presence of emerging pollutants that are not currently monitored in drinking water is a concern. There is also a concern regarding the quality of water from small supplies and private wells, although this represents a small proportion of the total supply.

- Releases of antibiotics via urban waste water treatment plants can significantly accelerate the emergence and spread of antimicrobial resistance. Infections caused by multidrug-resistant bacteria are estimated to cause 25 000 deaths in the EU every year.

Environmental health inequities

The most vulnerable people in our society are hardest hit by environmental stressors. Socially deprived communities are exposed to a higher burden of pollution, with citizens in poorer European regions exposed to high levels of air pollution and noise and to high temperatures. Poorer people, children, the elderly and people with ill health are more negatively affected than others by environmental health hazards. Higher levels of exposure to environmental stressors and the greater burden of health impacts exacerbate existing health inequities.

- Poorer people are disproportionately exposed to air pollution and extreme weather, including heatwaves and extreme cold. This is linked to where they live, work and go to school, often in socially deprived urban neighbourhoods close to heavy traffic. Dilapidated buildings allow outdoor air pollution to enter, are harder to keep at a comfortable temperature and are more likely to be damp and mouldy.

- For noise, the evidence is mixed, with exposure linked to local factors, in particular road traffic levels. In some cities, wealthier neighbourhoods are located in city centres, characterised by high noise levels, while other city centres suffer social deprivation.

- With regard to chemicals, the patterns of inequalities in exposure can vary, depending on the chemical, and are influenced by behaviours such as product use, dietary preferences and smoking, as well as housing quality. However, no groups escape chemical exposure, with exogenous chemicals detected in the blood and urine of over 90 % of pregnant women and children sampled in a pan-European study.

- Socially deprived people, children, the elderly and those with ill health are less resilient in terms of coping with or avoiding climate hazards, given that they have fewer resources to heat or cool their home and reduced mobility when faced with rising flood waters. Disadvantaged social groups take longer to recover and restore their homes from the impacts of floods and suffer greater mental health impacts.

- Certain groups are particularly sensitive to environmental stressors, including children, pregnant women, the elderly and those suffering from ill health. In particular, exposure to certain hazardous chemicals during critical windows of development in foetuses and young children can lead to irreversible effects. High proportions of pregnant women and children in European cities are exposed to air pollution and noise levels above health-based guidance values.

Green solutions offer a triple win — benefiting the environment, health and society

Protecting and restoring our environment, in particular within cities, can deliver positive outcomes for those living, working or spending their free time in these places. Green solutions, such as expanding high-quality green and blue spaces in urban areas, offer a 'triple win' by mitigating environmental pollution and supporting biodiversity, improving the health and well-being of urban populations and fostering social cohesion and integration. High-quality natural environments are a tool for disease prevention, reducing exposure to environmental stressors and promoting exercise, relaxation and social interaction in support of health and well-being.

- Reducing environmental pollution and creating healthier environments will yield significant benefits for the health of European citizens. While there are some gaps in our knowledge regarding the health effects of environmental stressors, the evidence base is sufficiently robust to justify taking action to tackle pollution today.

- In addition to reducing the number of premature deaths, access to healthier environments will also reduce the prevalence of health conditions that affect our daily quality of life, such as cardiovascular disease, stroke, asthma, hypertension, dementia, stress and heat exposure.

- High-quality natural environments offer health benefits through physical activity, relaxation and restoration and social cohesion, and by supporting the functioning of the immune system. These pathways deliver improved mental health and cognitive function, reduced cardiovascular morbidity, reduced prevalence of diabetes, improved maternal and foetal outcomes and overall reduced mortality.

- Green and blue spaces in local neighbourhoods provide particularly significant health and well-being benefits for low-income and deprived urban populations and can support the integration of marginalised social groups.

- There is significant variation in the accessibility of urban green spaces across Europe, which is linked to urban structure. Socially deprived groups tend to have reduced access to urban green space, with higher house prices in greener residential areas being a factor that drives unequal access.

- Green infrastructure can mitigate environmental stressors. Green and blue spaces offer cooling effects to tackle the urban heat island effect, and alleviate flooding. More stable urban temperatures reduce energy requirements for buildings. Green spaces can also reduce noise, particularly in built-up areas.

Integrated approaches to environment and health

Traditional approaches to the environment and health have predominantly focused on individual hazards in compartmentalised environmental media. Today, there is recognition that the dynamic between the environment, health and well-being is complex, with exposure to multiple stressors leading to combined effects, mediated by social status. The upstream drivers of environmental degradation are interconnected and may themselves have an impact on public health. For example, dependency on vehicular transport leads to sedentary lifestyles and associated ill health, as well as emissions of air pollutants and greenhouse gases.

Behaviour, diet and consumer choices play a significant role in mediating exposure to some environmental stressors and are influenced and sometimes constrained by socio-economic status. For example, fuel poverty is linked to the use of solid fuels for indoor heating and cooking, leading to poor indoor and ambient air quality.

Another challenge emerges from the fact that the drivers of environmental degradation may be dislocated in time and place from health outcomes. This is the case for climate change, emissions of transboundary pollutants — in particular persistent organic pollutants — and biodiversity loss. Such issues require coordinated international action, complemented by local efforts to raise awareness and support adaptive measures to reduce exposure to environmental stressors. Examples may include providing advice to local communities on avoiding growing vegetables in contaminated soil or promoting green space to mitigate the local effects of climate change. Similarly, integrated policies on urban transport and mobility can create multiple benefits, such as improving air quality, reducing noise exposure, increasing the availability of green spaces, reducing greenhouse gas emissions and increasing activity levels through cycling and walking for leisure and commuting.

The unequal impact of environmental pollution and degradation on socially deprived communities and vulnerable groups needs to be systematically addressed across policy domains. Universal measures to deliver overall reductions in exposure to environmental stressors for the general population can be complemented by measures targeted at groups known to be vulnerable in terms of their increased exposure, increased sensitivity or reduced resilience. At European level, options to target socio-environmental inequalities through the EU Cohesion Fund and the European Social Fund exist, since environmental inequalities follow the pattern of socio-demographic inequalities across Europe. At the local level, integrating environmental health concerns into welfare policies, health policies, and urban planning and housing policies can help to reduce the vulnerability and exposure of the population.

Health policies can also directly tackle the environmental, economic and social determinants of health, with the potential to reduce the burden of disease in the long term. In 2016, only 3 % of health expenditure was allocated to disease prevention. There is significant potential to reduce mortality and morbidity linked to environmental conditions by raising awareness among exposed communities, mitigating environmental stressors, supporting healthy behaviours, facilitating choices to use cleaner fuels and providing access to high-quality environments, in particular for socially deprived communities.

The need to tackle the upstream drivers of environmental degradation

At the same time, human activity continues to damage the European environment. Unless we make some fundamental changes to the key societal systems that drive environmental and climatic pressures, the prospects for our society are not positive. These key systems include our food, energy, mobility and production systems, as well as our consumption patterns and ways of life. Given the inherent links to human behaviour and consumption patterns, new citizen science initiatives provide a useful means of gathering data, engaging the public, and increasing awareness and action at the local and individual level.

The European Green Deal represents a sea change in the European policy agenda and sets out a sustainable and inclusive strategy to improve people's health and quality of life, care for nature, and leave no one behind. This includes a 'zero pollution Europe' ambition to protect citizens' health from environmental degradation, including air pollution, water pollution, noise and chemicals. This is complemented by the goal of achieving climate neutrality by 2050, an ambition that will require action across a range of systems and policy areas. Finally, the transition should be socially just, leaving nobody behind.

Achieving these goals at European level will require an integrated approach, with environmental and sustainability considerations being systemically addressed across policy areas. There are conflicting policy objectives, even within the environmental domain, where trade-offs need to be resolved. For example, efforts to reduce greenhouse gas emissions through the use of renewable biomass or through energy-efficient buildings with reduced ventilation can increase exposure to ambient and indoor air pollution. Pharmaceuticals are used extensively to support good health, while their release into the environment can have an impact on ecosystems, and, in the case of antibiotics, generate antimicrobial resistance. More broadly, economic growth is the principal means of poverty alleviation, but it is currently driven by unsustainable consumption and production, the root cause of environmental degradation.

The integration of environmental health concerns across a broad range of policy domains is critical to bringing about the changes needed to reduce exposure to environmental stressors and to fully realise the benefits that nature offers to support the health and well-being of the European population.

COVID-19 — considerations for environmental health

The COVID-19 pandemic provides a stark example of the inextricable links between human health and ecosystem health. This novel disease is thought to have emerged in bat populations, subsequently jumping species to infect humans in a seafood and animal market. The emergence of such zoonotic pathogens is linked to environmental degradation and human interactions with animals in the food system. Other factors, such as exposure to air pollution and social status, seem to affect transmission and mortality rates in ways that are not yet fully understood.

Aside from the emergence of COVID-19, other dimensions of our environment and our social organisation interplay with COVID-19 in ways that are not yet fully understood. These include environmental and social factors that influence human vulnerability and susceptibility to the disease, and in turn the environmental consequences of measures taken by society to manage the outbreak. It is clear that water, sanitation and hygiene facilities are key to preventing the spread of COVID-19, with waste water monitoring emerging as an effective tool for tracking the circulation of the virus.

The emergence of COVID-19

In December 2019, a cluster of pneumonia cases of unknown origin was identified in Wuhan, China. The virus was subsequently identified and named severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), with the resulting disease labelled coronavirus disease 2019 (COVID-19). The cluster was associated with a seafood and animal market, suggesting the disease was zoonotic in origin, meaning that it was transmitted to humans from animals. Zoonotic diseases emerge when a human is infected with novel microorganisms transferred from an animal reservoir, with transmission often occurring via an intermediary host, such as insect vectors or domesticated animals (UNEP, 2020).

The exact origin and natural reservoir of SARS-CoV-2 presently remains unknown, although bats have been considered likely suspects given the high prevalence of coronavirus in wild bat populations and similarities with the human SARS-CoV-2 virus (Wu, Y.C., et al., 2020). SARS-CoV-2 is the third known zoonotic coronavirus to infect humans in recent years. An earlier coronavirus, SARS-CoV, appeared in late 2002, transmitted to humans via masked palm civets. It caused the 2003 outbreak of severe acute respiratory syndrome (SARS) that spread out of China to affect 26 countries (WHO, 2020a). In the second instance, Middle East respiratory syndrome coronavirus (MERS-CoV), which was transmitted to humans via dromedary camels, was detected in the Middle East in 2012 and spread to 27 countries (WHO, 2019a). Both viruses are believed to have originated in bats (Mackenzie and Smith, 2020).

About 60 % of human infectious diseases are of animal origin (Woolhouse and Gowtage-Sequeria, 2005), while three quarters of new and emerging infectious diseases are transmitted to humans from animals (Taylor et al., 2001). These include viruses responsible for significant global mortality, such as the human immunodeficiency viruses (HIV) HIV-1 and HIV-2 that cause acquired immune deficiency syndrome (AIDS) and emerged from wild primate populations, the Rift Valley fever virus that jumped from infected livestock to humans, as well as influenza viruses that have emerged from domestic animals, in particular pigs and poultry, such as bird flu and swine flu. Other zoonotic diseases associated with particularly high fatality rates include the Ebola virus, Hantaviruses and Nipah virus (Wolf et al., 2005). In the mid-fourteenth century, the bubonic plague killed a third of Europe's population, caused by the bacteria Yersinia pestis and transmitted to humans from rodents via fleas (UNEP, 2020).

Prior to the COVID-19 outbreak in Europe, the most commonly reported zoonoses in humans were campylobacteriosis, salmonellosis, Shiga toxin-producing *Escherichia coli* and Yersiniosis, all of which have reservoirs in domesticated animals with transmission to humans associated with the consumption of contaminated food of animal origin. Of note, a large increase in human West Nile virus infections was reported in Europe in 2018, transmitted via the bites of mosquitos that had fed on infected wild birds (European Centre for Disease Prevention and Control, 2018).

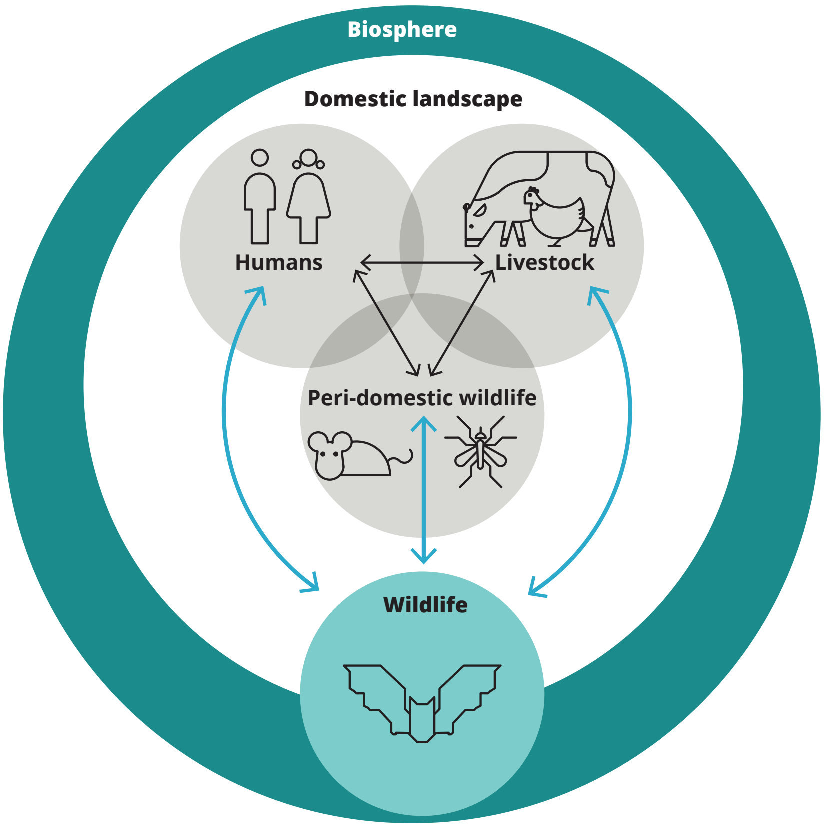
Novel viruses have emerged from intensive systems of domestic livestock rearing, where human and animal pathogens circulate and in some cases amplify. The intensive production of animal protein involves rearing concentrated populations of genetically similar animals in close proximity, often in poor conditions, fostering vulnerability to infection (UNEP, 2020). More than 50 % of zoonotic infectious diseases that have emerged since 1940 have been associated with measures to intensify agriculture, including dams, irrigation projects and factory farms (Rohr et al, 2019).

The use of land to produce animal feed is a key driver of deforestation (Nepstad et al., 2014). There is a clear link between tropical deforestation and the emergence of zoonotic viruses from reservoirs in wildlife. Forest clearance for roadbuilding, mining and agriculture, along with the hunting of wildlife for meat and traditional medicine, and the use of wildlife as pets, all result in a greater frequency of human-wildlife interactions that can provide a launch pad for novel human viruses (Dobson et al, 2020). Land use change, including the conversion of natural ecosystems for agriculture or urban development, has been found to impact species diversity and abundance, favouring animal species that act as reservoirs for zoonotic disease, in particular rodents, bats and passerine birds. As such, global changes in land use are expanding the interfaces between people, livestock and the wildlife reservoirs of zoonotic disease (Gibb et al, 2020) (see Figure 0.1).

In their recent report, the United Nations Environment Programme and the International Livestock Research Institute (2020) identify seven major anthropogenic drivers of zoonotic disease emergence, including:

- Increased demand for animal protein;
- Unsustainable agricultural intensification;
- Increased use and exploitation of wildlife;
- Unsustainable utilisation of natural resources accelerated by urbanisation, land use change and extractive industries;
- Travel and transportation;
- Changes in food supply chains;
- Climate change.

Figure 0.1 Zoonotic disease transmission at the interface between humans, livestock and wildlife



Source: Adapted from Jones et al. (2013).

The report advocates the One Health approach, bringing together medical, veterinary and environmental expertise to deliver optimal health for humans, animals and the environment and prevent zoonosis. Recognising the potential for zoonotic disease to spill across these compartments, the management of human and ecosystem health requires an integrated approach built upon knowledge created through multi-disciplinary collaboration. There is a need to improve our understanding not just of the pathogens that cause disease, but also the complex environmental and social dimensions that influence the spread of disease. Increased surveillance of zoonotic disease across different habitats is needed to understand the role that environmental degradation plays in driving disease emergence. Finally, the severity of the COVID-19 pandemic should renew efforts to address the drivers of emerging infectious disease, in particular the structure of the food system and demand for animal protein (UNEP, 2020).

Vulnerability and susceptibility to COVID-19

Researchers are exploring the role that air pollution may play in influencing the severity of COVID-19. Exposure to air pollution is associated with cardiovascular and respiratory disease, both pre-existing health conditions identified as risk factors for death in COVID-19 patients (Yang et al., 2020). As such, long term exposure to air pollution might be expected to increase susceptibility to COVID-19 in individuals, with previous studies having, for example, demonstrated a role for exposure to particulate matter (PM) in worsening the impact of respiratory viruses (Sciomer et al., 2020).

Some recent studies have explored the evidence for links between air pollution and high mortality rates for COVID-19. An Italian study argued that since long-term exposure to air pollution, including PM, ozone (O_3) and sulfur dioxide (SO_2), weakens the immune defences of the upper airways, this would facilitate entry of the SARS-CoV-2 into the lower airways resulting in infection with COVID-19. They therefore suggest that air pollution should be considered a co-factor in the high level of fatality in Northern Italy (Conticini, et al., 2020).

An additional study significantly correlated air pollution over the past 4 years with cases of COVID-19 in up to 71 Italian provinces and suggested that chronic exposure provides a favourable context for the spread of the virus (Fattorini and Regoli, 2020). A US study explored associations between long-term exposure to fine particulate matter ($PM_{2.5}$) and an increased risk of death from COVID-19 in the US, and found a small increase in concentration (1 $\mu g/m^3$) to be associated with an 8 % increase in the death rate (Wu, X., et al., 2020). In follow up, a similar study from the Netherlands investigated the relationship between long-term exposure and COVID-19 in 355 Dutch municipalities and found a 1 $\mu g/m^3$ increase in $PM_{2.5}$ concentrations to be associated with an increase in the death rate of between 13 % and 21.4 % (Cole, et al., 2020). Finally, an English study found deaths from COVID-19 to be more common in highly polluted areas, although the correlation between the risk of death and pollution weakened as the disease spread out of urban areas. The analysis found that long-term exposure to $PM_{2.5}$ could increase the risk of contracting and dying from COVID-19 by up to 7 %. Of note, over one third of the patients that died from COVID-19 suffered from pre-existing respiratory or cardiovascular disease (Office for National Statistics, 2020).

Of relevance, an earlier study assessed the influence of long- and short-term exposure to air pollution on mortality rates in China during the 2003 SARS outbreak and demonstrated a positive association between air pollution and fatality. Patients from regions with poor air quality were twice as likely to die as those from regions with low levels of air pollution, with associations found for both long- and short-term exposure (Cui, Y. et al., 2003).

There are, however, a number of significant limitations with these early studies and so findings need to be interpreted with care. Such limitations include the frequent lack of reliable and consistent data on mortality rates in different regions, and challenges in effectively controlling for numerous confounding factors, such as government measures to control transmission, population structure, international connectivity of the community, and social and individual behaviours such as smoking. Spatial coincidence alone cannot be taken as causality, with further epidemiological research required to elucidate possible causal associations between past exposure to air pollution and COVID-19 health impacts.

An additional public health question, also currently being researched, is whether particulate matter can transport the virus. In Italy, genetic material from the SARS-CoV-2 virus was detected on PM samples from the city of Bergamo in Northern Italy (Setti, et al., 2020). While there are some concerns that air pollution could carry the virus over longer distances and drive infection, at this stage it is not known whether the virus remains viable on pollution particles. Again, further research is required.

Chemical exposure has been indirectly linked to vulnerability to COVID-19. Certain chemicals are associated with health impacts such as obesity, cardiovascular diseases, immunotoxicity and respiratory diseases that have, in turn, been found to increase susceptibility to COVID-19. As such, the assumption is that individuals with such pre-existing health conditions resulting from chemical exposure may have increased susceptibility to COVID-19. In this context, a recent study has suggested that long-term, low-dose exposure to mixtures of chemicals may lead to immunodeficiency in the face of epidemics and pandemics (Tsatsakis, et al., 2020).

In terms of the role of social factors in the COVID-19 pandemic, residents in care homes are a particularly vulnerable population group. At the same time, emerging evidence suggests that deprived communities are more likely to contract COVID-19. In a recent Swedish study, 4.1 % of residents of a high-income area of Stockholm tested positive for SARS-CoV-2-specific antibodies, in contrast to 30 % of residents of a low-income area. Possible explanations for the difference include cramped housing conditions, working conditions and challenges for migrant communities in understanding public health advice delivered in Swedish (Lundkvist et al., 2020). A Spanish study assessed the relationship between income and incidence of COVID-19 in Barcelona and found that districts with the lowest mean income had the highest incidence of COVID-19, with the lowest income district exhibiting an incidence 2.5 times greater than that of the highest income district (Baena-Díez et al., 2020).

Several factors may increase the vulnerability of people of low socio-economic status, both in terms of exposure to the virus and the severity of outcomes. In terms of exposure, poorer people are more likely to live in poor quality, overcrowded accommodation, jeopardising compliance with social distancing recommendations and increasing the risk of transmitting infection. Secondly, poorer people often have jobs that cannot be carried out from home, such as working in healthcare, care homes, supermarkets, factories, warehouses, and public transport. Thirdly, poorer people are more likely to have unstable work conditions and face financial uncertainty due to the economic impacts of the response to COVID-19. Such individuals face significant pressures to continue working even when ill, in order to safeguard household incomes. This can influence the severity of outcomes, whereby sustained stress weakens the immune system, increasing susceptibility to a range of diseases (Patel, et al., 2020). In addition, poorer people in urban areas are likely to be exposed to higher levels of air pollution and noise, associated with respiratory and cardiovascular diseases, and hypertension respectively (EEA, 2018a), while hypertension and diabetes are directly associated with poverty. These conditions are all risk factors for death from COVID-19 (Yang et al., 2020), suggesting that people of low socio-economic status have an increased susceptibility to COVID-19 mortality (Patel, et al., 2020).

There is emerging evidence that ethnicity may play a role in vulnerability to COVID-19, with black, Asian and minority ethnic (BAME) individuals at an increased risk of acquiring SARS-CoV-2 infection compared to white individuals, and of worse clinical outcomes from COVID-19 (Pan et al., 2020). The English study mentioned above found ethnicity to be strongly correlated with pollution exposure, with BAME individuals more likely to live in polluted inner-city areas than their white counterparts. However, air pollution was not thought to be the sole driver behind disparities in mortality rates across ethnic groups (Office for National Statistics, 2020). Further research is required to disentangle the respective roles of ethnicity and air pollution in driving COVID-19 infection and mortality rates.

Across Europe, particular concern is increasingly focused on the most vulnerable, who may already struggle with pre-existing health conditions and high levels of stress, and in some cases have limited access to sanitation, making good hand hygiene more difficult. This includes homeless people, migrants and asylum seekers living both informally and in reception camps, prison populations and disadvantaged Roma communities.

Prevention and surveillance – the role of WASH

The World Health Organization has highlighted the essential role of water, sanitation and hygiene (WASH) in preventing the spread of COVID-19, with frequent and correct hand hygiene one of the most important measures to prevent infection. Ensuring the availability of WASH and, in particular, sustained access to hand hygiene facilities in communities, homes, schools, marketplaces, and healthcare facilities will help prevent human-to-human transmission of SARS-CoV-2 (WHO, 2020b).

Regarding the question of whether the virus can be transmitted via water, existing research finds no indication that SARS-CoV-2 can persist in drinking water. To date, neither untreated nor treated sewage have been reported as a route of infection (WHO, 2020b).

Monitoring untreated waste waters is emerging as a tool in public health surveillance for COVID-19, providing a good indicator of the presence of the virus in a population. Studies in a number of countries have detected fragments of SARS-CoV-2 RNA in untreated sewage and sludge (La Rosa, G., et al., 2020, Medema et al., 2020, Peccia et al., 2020, Randazzo et al., 2020, RIVM, 2020). Researchers have established that the concentration of viral RNA in untreated sewage increases with the level of infection in the catchment population (Medema et al., 2020). In addition, results suggest that SARS-CoV-2 RNA concentration in wastewater is a leading indicator of community infection, ahead of COVID-19 testing data and local hospital admissions (Peccia et al., 2020). As an example, SARS-CoV-2 RNA was detected in waste water dating from before the first cases were reported in Spain (Randazzo et al., 2020). This suggests that waste water surveillance of SARS-CoV-2 can complement public health data as a sensitive tool for tracking the circulation of the virus in urban areas in Europe, as well as providing an early warning indicator of re-emergence.

In order to support and coordinate these efforts, the European Commission has launched a pan-European Umbrella Study to assess the feasibility of developing a waste water monitoring system for SARS-CoV-2. The activity aims to exchange knowledge and develop standardised analytical methods and data interpretation to allow for comparison across ongoing research activities, with 20 countries involved to date (JRC, 2020).

Impacts of measures to control COVID-19 transmission

The lockdown measures put in place to control the transmission of COVID-19 have had implications for environmental health. The requirement to stay at home can negatively impact on health and mental well-being: the extent to which such impacts may occur can depend on the size of the home and the number of residents, access to personal outdoor space and access to green and blue spaces in the local area. Wealthier households are more likely to have private gardens and live in leafy suburbs with access to parks. In terms of chemical exposure, the pandemic-induced confinement increases exposure to indoor air pollution. Concerns with the overuse and/or misuse of disinfectants and other indoor chemical exposure which could also affect health have been raised in certain scientific communities. At this stage, there is little hard data to back up these suggestions, and further research is required.

In terms of how lockdown measures have impacted environmental conditions in Europe, reductions in economic and social activities led to significant decreases in certain types of pollution. Across Europe, the lockdown measures resulted in large decreases in air pollutant concentrations — nitrogen dioxide (NO_2) concentrations in particular — largely due to reduced traffic and other activities, especially in major cities. The extent of reductions varied considerably, with the largest reductions of up to 70 % seen in urban centres in those countries most affected countries by COVID-19 in the spring of 2020, namely Spain, Italy and France. Concentrations of coarse particulate matter (PM_{10}) also fell across Europe, although to a lesser extent than NO_2. The greatest reductions are estimated to have been in cities in Spain and Italy (EEA, forthcoming). These reductions were short lived, with levels of air pollution rebounding as lockdowns were eased and vehicular transport resumed across Europe.

It is likely that there has also been a significant drop in noise levels during the COVID-19 lockdown, as noise pollution from traffic are typically correlated with NO_2 levels. While we have grown accustomed to unhealthy noise levels in cities, the short-term reduction in noise during lockdown allowed people to experience the immediate benefits of quieter cities.

The COVID-19 crisis has also had a direct impact on global and EU greenhouse gas (GHG) emissions, although we will only be able to fully quantify its magnitude after 2020.

However, as economic activity picks up these short-term environmental benefits are likely to be reversed. Improving environmental health requires long-term systemic change to the upstream drivers of environmental pollution, including our mobility, food, and production and consumption systems.

The lockdown has changed working conditions for many people, with a significant increase in the number of people working from home and a reduction in business travel. Knock-on effects may include an increase in demand for housing outside of city centres. In many cities, road space was allocated to cyclists and pedestrians during the lockdowns when traffic levels fell. These factors are feeding into discussions on how to increase the sustainability and resilience of cities and avoid a return to pre-COVID-19 'business as usual'. At the same time, concerns regarding transmission of COVID-19 on public transport may lead to an increase in the use of private vehicles for daily commutes, as people seek to avoid exposure.

Finally, the use of personal protective equipment in healthcare facilities, care homes and other front-line activities, as well as public use of masks, now mandatory in certain countries and contexts, has driven a sharp increase in the use of single-use plastics and resulting waste. In addition, the low price of crude oil has reduced demand for recycled plastics, as virgin plastic can be produced at a lower cost.

EU response to COVID-19

The COVID-19 pandemic is testing social resilience in Europe. In terms of the immediate response, the European Commission recently published a communication on 'Short-term EU health preparedness for COVID-19 outbreaks' (EC, 2020a), setting out lessons learnt to date and outlining key measures to be taken in the coming months. Regarding public health surveillance for COVID-19, the communication recommends that activities explore changes in the prevalence across risk groups, including investigating the role of environmental exposure. It calls for the creation of an open access EU level register for the prevention and reduction of epidemiological risks, to cover the environmental determinants of health. The communication also recognises the role, within public health surveillance, of monitoring COVID-19 residues in wastewaters, with action already underway to coordinate and harmonise monitoring activities. The European Commission is also investing in research to prepare for and respond to this type of public health emergency, with two research calls to date focussed on COVID-19 under the EU research and innovation programme, Horizon 2020.

For the longer term, with the European Green Deal the European Commission has already proposed an ambitious and just transition towards long-term sustainability, placing environment and climate concerns at its centre. It recognises how good health is inextricably connected to the state of our environment and aims to protect the health and well-being of citizens from environment-related risks and impacts (EC, 2019). Major policy packages, including the recently proposed Biodiversity Strategy (EC, 2020b) and the Farm to Fork Strategy (EC, 2020c), have been put forward to implement this vision. A forthcoming initiative, expected in 2021, will detail the zero-pollution ambition for Europe.

These priorities are also clearly reflected in the multi-annual EU budget proposal of EUR 1.1 trillion for 2021-2027. As part of a recovery plan from this economic crisis, a new, additional financial instrument called 'Next Generation EU', amounting to EUR 750 billion, was recently proposed by the European Commission. Framed within well-defined policy targets, these funds can help Europe transform its economy while achieving climate-neutrality and sustainability, and addressing social inequalities (EC, 2020d). The delivery of ambitions to tackle the systemic interlinkages across environmental and ecosystem health will require collaboration across a broad range of policy areas and at multiple levels of governance.

At global level, in May 2020 the World Health Organization issued the 'WHO manifesto for a healthy recovery from COVID-19' that sets out the lessons learnt from COVID-19 and identifies key elements of a healthy, green recovery. These include protecting nature, making cities more liveable and improving essential services, as well as addressing the upstream drivers of poor environmental health by promoting sustainable energy and food systems, and eliminating subsidies for fossil fuels (WHO, 2020c).

Regarding the prevention of future zoonotic infectious disease, the One Health approach provides a framework for communication and cooperation across multiple sectors as a means of integrating human, animal and environmental health, explicitly addressing the connections across these domains. The need to respond to the current crisis, and to prevent future pandemics, provides a strong rationale for an integrated approach to human and environmental health.

1 Introduction

1.1 The environment, health and well-being nexus

The health and well-being of European citizens are determined by aspects of their everyday life, including economic circumstances, social dynamics and the quality of their natural and living environments. These different dimensions are not isolated but interact in a complex nexus to deliver a living experience specific to each individual. This report explores the influence of the environment on health and well-being, and how socio-economic factors mediate this influence.

Spending time in high-quality natural environments fosters good health and well-being (Prüss-Ustün et al., 2016; ten Brink et al., 2016; Lovell et al., 2018). Nature supports life through a broad range of ecosystem services, including provisioning services, such as fresh water, regulating services, such as pollination and climate regulation, and cultural services that provide opportunities for recreation and relaxation.

At the same time, a significant proportion of the burden of disease in Europe is attributed to environmental pollution resulting from human activity. Data from the World Health Organization (WHO) indicate that in 2012, environmental stressors were responsible for at least 13 % of all deaths in the 28 Member States of the EU (EU-28), which equates to a total of 630 000 deaths attributable to the environment (WHO, 2016a). Just over a third of cases of ischaemic heart disease and 42 % of strokes could be prevented by reducing or removing exposure to chemicals from ambient air pollution, household air pollution, second-hand smoke and lead (Prüss-Ustün et al., 2016). At a global level, a recent assessment attributed 16 % of total mortality to pollution-related disease (Landrigan et al., 2018). In the EU, air pollution and extreme weather conditions are recognised as risk factors driving excess mortality (OECD and EU, 2018). In this context, preventing exposure to environmental risks would significantly reduce the environmental burden of disease.

While all citizens are affected by environment risks, socially disadvantaged and vulnerable groups are disproportionally affected, exacerbating existing inequalities (WHO Europe, 2019a). Socially deprived communities are exposed to a higher burden of pollution, with citizens in poorer European regions exposed to high levels of air pollution and noise and to high temperatures. In addition, groups of lower socio-economic status tend to be more negatively affected by these environmental health hazards (EEA, 2018a).

People with pre-existing health conditions, children and the elderly are more sensitive to the impact of environmental stressors, such as air pollution and noise. Poorer communities are also more vulnerable, being less able to afford to protect themselves from environmental stressors, for example by installing air conditioning during hot summers. They are less likely to restore their homes after flooding or move to a new house to avoid future floods (EEA, 2018a). As a result, poorer communities are more exposed, sensitive and vulnerable to environmental risks, less resilient in terms of adapting to and avoiding risks, and recover more slowly from the impacts of environmental stressors.

Given their increased vulnerability, poorer communities benefit significantly from the benefits offered by access to high-quality environments. This is particularly true for people in socially deprived urban communities, who tend to live in densely populated urban spaces, with reduced access to the benefits of high-quality environments in Europe (WHO Europe, 2019a). In many European countries, the disproportionate exposure of lower socio-economic groups to air pollution, noise and high temperatures occurs in urban areas (EEA, 2018a).

Demographics play an important role in determining the distribution of environmental health impacts. Across Europe, the elderly, children and those with poor health tend to be more adversely affected by environmental health hazards than the general population. There are also environmental inequalities linked to ethnicity, with Roma communities in Central and Eastern Europe often excluded from basic services and exposed to environmental pollution, with serious health consequences (Heidegger and Wiese, 2020). Individual behaviours also influence exposure and sensitivity to environmental stressors (Staatsen et al., 2017). For example, dietary choices influence exposure to chemicals, while smoking can make an individual more vulnerable to the health impacts of air pollution.

In 2013, the European Environment Agency (EEA) and the European Commission's Joint Research Centre (JRC) produced a joint report on the environment and health and concluded that an approach focused on controlling single environmental hazards is insufficient to address interconnected challenges such as climate change, ecosystem degradation, the obesity epidemic and persistent social inequality. The report called for an integrated approach to assessing the environment, health and well-being nexus, one that recognises the impact of multiple environmental stressors and captures social dimensions, consumption patterns and the benefits delivered by the environment (EEA and JRC, 2013).

1.2 The policy framework for environment, health and well-being

The 2030 agenda for sustainable development, adopted by all United Nations (UN) Member States in 2015, sets out goals and targets for action over the next decade. The 17 Sustainable Development Goals (SDGs) address multiple aspects of human development, including improved health, poverty alleviation, education, reduced inequality and economic growth, environmental quality and the urgent need to tackle climate change. SDG 3 aims to guarantee good health and well-being for all at all ages, with a particular focus on reducing maternal and child mortality. It includes the goal of ending the epidemic of communicable disease and reducing premature mortality from non-communicable diseases by one third through prevention and treatment. In particular, it aims to deliver a substantial reduction in deaths and illnesses stemming from hazardous chemicals and air, water and soil pollution and contamination, recognising that environmental improvements deliver improved health.

In fact, as shown in Figure 1.1, the environmental and social determinants of health are themes that thread through the SDGs, providing opportunities for synergies in planning actions to deliver on relevant goals and targets. At the same time, there are also conflicts across the SDGs that demand trade-offs. In particular, the current paradigm of economic growth driven by increasing consumption and production has delivered poverty alleviation but at the same time has also driven environmental degradation (EEA, 2019a).

At the pan-European level, the European environment and health process brings together policymakers from the health and the environment domains to shape policies and actions on the environment and health. Agreed in 2017, the Ostrava Declaration summarises the priorities in these areas in the WHO European region, resolving to protect and promote health and well-being and prevent premature deaths, diseases and inequalities related to environmental pollution and degradation (WHO Europe, 2017a).

In the EU, the ambitious new agenda of the European Commission, the European Green Deal, recognises that good health is closely connected to the state of our environment and aims to protect the health and well-being of citizens from environment-related risks and impacts. Under the European Green Deal, the Farm to Fork Strategy aims to deliver a sustainable food system that will yield environment and health benefits, as well as securing livelihoods for European farmers (EC, 2020b). The recent EU Biodiversity Strategy for 2030 highlights the importance of nature for our mental and physical wellbeing, as well as for social resilience, and identifies the urgent need to protect and restore nature in the light of the COVID-19 pandemic (EC, 2020c). The need to reduce the environmental impacts of production and consumption is recognised by the Circular Economy Action Plan, which aims to prevent waste and promote circularity in production processes, while ensuring the delivery of safe and sustainable products to European consumers (EC, 2020e).

Regarding action on climate change, the Commission proposes to enshrine the objective of reaching climate neutrality by 2050 in legislation, and increase the EU's greenhouse gas emission reductions target for 2030 (EC, 2020f). On adaptation, the European Green Deal recognises the role of nature-based solutions.

The agenda includes a zero pollution ambition for a toxic-free environment, to be delivered through an action plan for air, water and soil, as well as a chemicals strategy for sustainability. It aims to accelerate the shift to sustainable and smart mobility, providing users with cleaner, healthier transport alternatives. The agenda also calls for a just and inclusive transition that leaves nobody behind (EC, 2019a).

The Treaty of Lisbon stipulates that a 'high level human health protection shall be ensured in the definition and implementation of all Union policies and activities' (EU, 2007). Member States are primarily responsible for organising and delivering health services and medical care, with EU action complementing national action and ensuring that health protection is embedded in all EU policies. The European Commission's 2013 staff working document 'Investing in health' recognises the inherent value of health as a dimension of human capital and a precondition for economic prosperity. It notes that disease prevention and health promotion

Figure 1.1 Environment and health in the SDGs

Sources: Based on WHO infographic *Health in the SDG era* and United Nations (2019).

offer significant public health gains and that addressing the risk factors that determine a population's health can reduce chronic disease and the associated healthcare costs and prevent premature deaths.

The health-in-all-policies approach aims to influence the environmental, economic and social determinants of health and has the potential to reduce the burden of disease in the long term (EC, 2013a). However, in

2016 only 3 % of health expenditure was allocated to prevention programmes, with close to 70 % spent on curative and rehabilitative care and medical goods (Eurostat, 2019a).

Regarding the policy framework for the environment in Europe, as identified in the Treaty of Lisbon, the EU wants to ensure that there is 'a high level of protection and improvement of the quality of the environment' (EU, 2007), whereby European citizens benefit from a minimum environmental quality, delivered through thematic policies on air and water pollution, environmental noise, chemicals and climate change. Environmental legislation acknowledges the role of the environment in determining public health outcomes, with the Seventh Environment Action Programme (7th EAP) aiming to safeguard EU citizens from environment-related pressures and risks to health and well-being by setting the following goal: 'in 2050, we live well, within the planet's ecological limits'. The 7th EAP explicitly recognises that sensitive or vulnerable groups may be more affected by pollution, particularly in cities, and that green infrastructure and blue spaces can deliver public health benefits (EU, 2013a).

Nevertheless, policies to address environmental health at EU level remain fragmented. Single environmental stressors are, for example, addressed through policies such as directives on air quality (EU, 2004, 2008a), the Environmental Noise Directive (EU, 2002) and the Water Framework Directive (EU, 2000). There is currently no overarching framework at EU level that can address the complex interlinkages across policy domains that are relevant to the environment and health. Relevant policy domains are those addressing the contextual dimensions that influence exposure to environmental risks, such as social inequity and urban structure, and the upstream sources of these risks, such as emissions from agriculture, industry, energy and transport.

The link between society, the environment and health has been touched on in recent cross-cutting policy frameworks. The Urban Agenda for Europe acknowledges the structural dimensions of poverty in deprived urban neighbourhoods and calls for integrated approaches to urban regeneration, with a focus on air pollution and the social dimension of climate adaptation strategies (EC, 2016a). The recent evaluation of the EU adaptation strategy highlights the areas in which the strategy may be able to deliver more in the future, including a focus on social vulnerability in adaptation policies and more explicit links between health and climate change (EC, 2018a). The EU green infrastructure strategy emphasises the role that green spaces in urban areas play in building communities and combating social exclusion (EC, 2013b).

1.3 Objectives of this report

This report consolidates available evidence of how the quality of the environment influences our health and well-being and explores how social factors mediate this influence, including social deprivation, behaviours and shifting demographics in Europe.

The overall goal of this report is to provide a knowledge base to support the development of integrated policies that address the environment, health and well-being nexus. The specific objectives of the report are as follows:

- to contextualise the influence of the environment on health and well-being within a broader picture of health across Europe;
- to assess the direct benefits that access to high-quality environments deliver for health and well-being;
- to review the social distribution of access to high-quality environments and the resulting benefits for health and well-being;
- to present the latest evidence on the health impacts of exposure to ambient and indoor air pollution, environmental noise, water pollution, climate change, electromagnetic fields and chemicals in Europe, including a reflection on the latest evidence regarding the synergistic effects of multiple stressors on health;
- to consider how social status mediates the impact of environmental stressors on health, including increased exposure, sensitivity and vulnerability; this includes a reflection on how individual behaviours can influence both exposure and vulnerability to environmental stressors;
- to reflect on the implications that this knowledge has for policies in the environment, health and well-being nexus, as well as broader sectoral policies;
- to identify gaps in knowledge and point to areas in which further research is needed.

1.4 Conceptual and analytical approach

The interactions through which the environment influences health and well-being and the dynamics through which social, economic and demographic factors mediate this influence are complex. To make sense of available evidence, practitioners in the field have proposed a framework that depicts the multiple variables at work within the environment, health and well-being nexus and that illustrates the causal relationships between them. The ecosystems-enriched drivers, pressures, state, exposure, effect, actions (eDPSEEA) model uses the concept of ecosystem services to emphasise how the quality of the environment is critical to human health and well-being (Reis et al., 2015). The practical application of the model to policy making is considered in Box 1.1.

The eDPSEEA model is shown in Figure 1.2 and depicts how upstream drivers influence the environmental state, leading to exposures that, in turn, affect health, either positively or negatively. The model places the environment-health interaction in a socio-economic context, capturing the influence of factors such as demography, social deprivation and behaviours. Dimensions of social status that may either cause certain groups to be vulnerable to environmental stressors or affect access to environmental benefits are systematically explored in this report.

The causal chain, from drivers and pressures to health impacts, may operate at multiple levels. For example, at the local level in a city, transport emissions drive poor air quality, which has an impact on the respiratory health of local residents. At the global level, emissions of greenhouse gases drive weather events related to climate change, reducing agricultural production and causing prices of staple foods to increase.

Distinct environmental stressors may have common upstream drivers, enabling the identification of co-benefits in policy actions. For example, both noise and air pollution results from vehicular transport. Conversely, certain solutions may entail trade-offs, such as the use of biofuels, which presents a trade-off between reducing greenhouse gas emissions and reducing air pollution. The framework illustrates how policy actions can target different intervention points in the system. Interventions may generate 'knock-on' effects for other environmental dimensions, highlighting the trade-offs and synergies inherent in policy decisions.

The analytical approach taken by this report is to focus primarily on the effect and exposure dimensions of the eDPSEEA model and consider the influence of social context. State, pressures and drivers are addressed only superficially. Extensive information on state, pressures and drivers is provided in various EEA reports on specific dimensions of environmental quality as well as in the EEA report *The European environment — state and outlook 2020* (EEA, 2019a). The current report complements this 2019 EEA report with a more detailed review of the evidence of how environmental quality affects health and well-being, both positively and negatively.

Evidence of how the environment influences health is presented from multiple scales. In the case of environmental benefits for health and well-being, the report presents quantitative evidence of access to high-quality environments, with a focus on urban areas, and considers qualitative evidence of the direct benefits for health and well-being from epidemiological studies. Regarding environmental risks, it combines quantitative evidence of exposure to and the health impacts of environmental stressors at the European level. This is complemented by qualitative evidence from smaller scale studies, with a focus on the urban environment in which people and multiple environmental risks are concentrated. Pertinent studies of the links between the environment, health and well-being at national and local levels, as well as policies and measures to

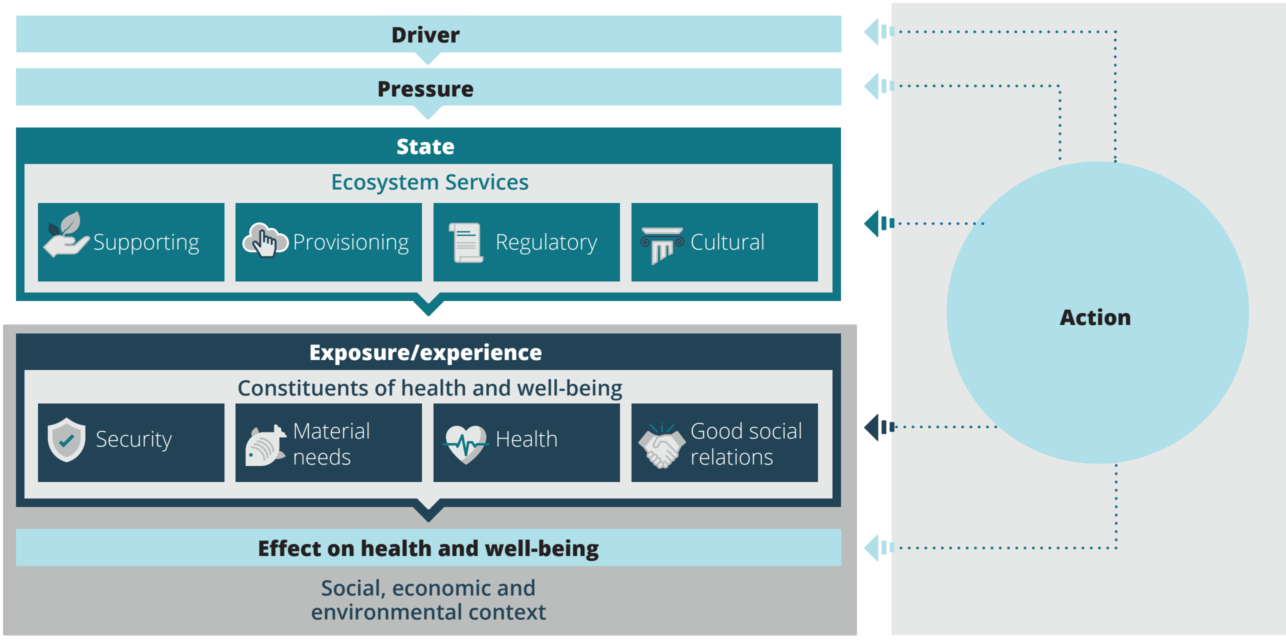
Box 1.1 Applying the DPSEEA model

The drivers, pressures, state, exposure, effect, actions (DPSEEA) model and variations of the model are widely applied in assessing links between the environment and health. The Scottish Government introduced a policy initiative on the environment and human health — good places better health — which used a modified DPSEEA model. The model offered a policy-relevant way of capturing cultural, economic and demographic drivers that shape the environment, as well as social and demographic factors that influence exposure and health outcomes (positive or negative) for the individual.

The modified DPSEEA model also proved to be a useful 'tool to think with', and during the process of populating the model, it facilitated stakeholder engagement and consensus building. The populated models, in turn, informed structured literature reviews and the assembly of a wider range of evidence and acted as a framework for data gathering and as a basis for quantification. The overall approach allowed health-relevant messages to be distilled for a broad policy constituency.

Source: Reis et al. (2015).

Figure 1.2 The eDPSEEA model



Source: Adapted from Reis et al. (2015).

promote good environmental health, are highlighted throughout the report.

The eDPSEEA model builds on work that was done under the millennium ecosystem assessment to map the ecosystem services provided by natural capital and identify their contribution to the key constituents of human well-being (Millennium Assessment Board, 2005). Nature delivers a broad range of ecosystem services that support human life, providing food and water, regulating our climate to support life and providing a basis for the cultural and aesthetic fabric of society. The different ecosystem services that support the various constituents of human well-being are shown in Figure 1.3.

This report does not comprehensively review how the full range of ecosystem services delivers benefits for health and well-being. Rather, it reflects on how environmental quality affects the delivery of certain services, leading to direct effects on human health and well-being. The services touched on in this report include:

- the provision of clean air, drinking water and food;
- the cultural and recreational value of access to high-quality nature;
- the regulation of the climate on multiple scales.

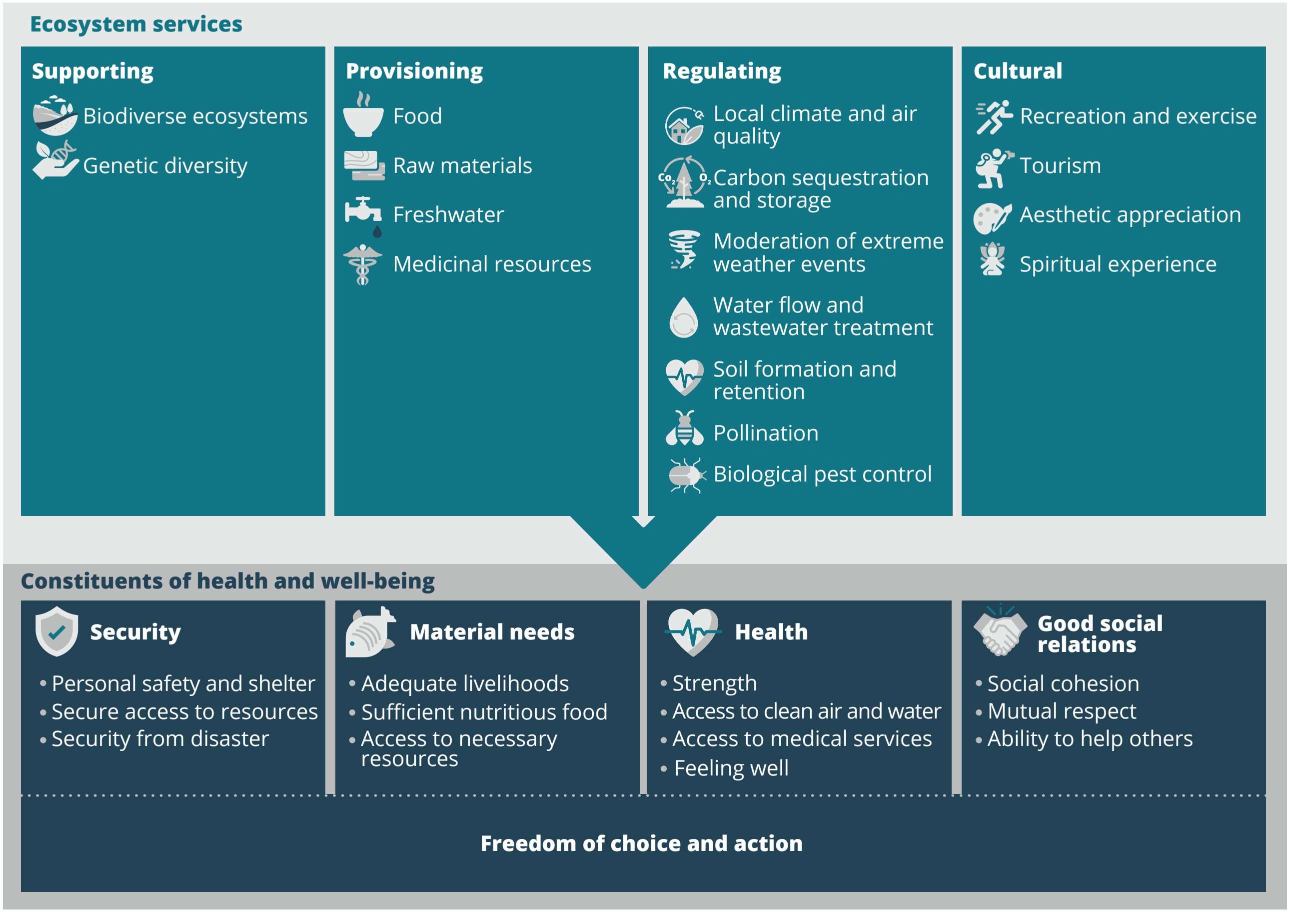
Regarding the geographical scope covered by this report, when presenting data, we refer to three different groups of countries. These include the EU-28, the 33 member countries of the EEA (EEA-33) and the EEA-33 plus six additional cooperating countries of the EEA (EEA-39).

The information presented in this report relates to the time period prior to the withdrawal of the United Kingdom from the EU and as such we refer to the EU-28 and include data for the United Kingdom in the analysis. The EU-28 Member States refers to Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom.

The additional member countries in the EEA-33 are Iceland, Liechtenstein, Norway, Switzerland and Turkey.

The additional six cooperating countries in the EEA-39 are Albania, Bosnia and Herzegovina, Kosovo (under UN Security Council Resolution 1244/99), Montenegro, North Macedonia and Serbia.

Figure 1.3 Ecosystem services and their input into the constituents of well-being



Source: Based on Millennium Assessment Board (2005).

2 Health across Europe

Key messages:

- Overall, 13 % of deaths in the EU are attributable to environmental stressors, a total of 630 000 deaths per year; this is based on the most recent World Health Organization environmental burden of disease data for 2012. These deaths could be prevented by eliminating environmental risks to health and reversing environmental degradation.
- In Europe, 90 % of deaths attributable to the environment result from non-communicable diseases, including cancers, cardiovascular diseases, stroke, chronic obstructive pulmonary disease, mental, behavioural and neurological disorders, diabetes, kidney disease and asthma.
- There is a significant discrepancy between the east of Europe and the west of Europe. The highest proportion of deaths attributable to the environment is seen in Bosnia and Herzegovina (27 %) and the lowest is seen in Norway and Iceland (9 %). In the EU, the highest environmental contribution to mortality is seen in Romania (19 %) and the lowest in Sweden and Denmark (10 %).
- There are substantial health inequalities, both within and between European countries. Environmental inequalities contribute to driving health inequities in Europe.
- Poorer people live shorter lives with fewer healthy life-years, have poorer self-perceived health and have a higher prevalence of long-term health problems.
- Key demographic factors influencing the health of the European population include the ageing population, migration and a high level of urbanisation.
- Socio-economic status is linked to certain unhealthy behaviours, with lower socio-economic groups more likely to have poorer diets, be overweight, exercise less and smoke. These behaviours have an impact on health and make people more sensitive to environmental risk factors.

This chapter provides a snapshot of the environmental burden of disease and mortality in Europe. It then goes on to consider health across Europe by using key indicators. It presents evidence of how socio-economic, behavioural and environmental factors affect health. The aim is to provide the overall context before providing a more detailed examination of how environmental conditions influence health in Chapter 4.

Environmental stressors are responsible for 13 % of all deaths in the EU, with 630 000 deaths attributed to the environment annually; this is based on the most recent World Health Organization (WHO) data available on the environmental burden of disease for 2012 (WHO, 2016a). These deaths could be prevented by eliminating pollution and environmental degradation. Eastern European countries carry a significantly higher environmental burden of disease and mortality than western European countries, exacerbating economic inequalities across the European region.

According to World Health Organization data, the European Region is the region in the world that is most affected by non-communicable diseases, with a relatively small group of health conditions responsible for a large part of the disease burden. The major non-communicable diseases (diabetes, cardiovascular diseases, cancer, chronic respiratory diseases and mental disorders) together account for an estimated 86 % of the deaths and 77 % of the disease burden in the European Region. These diseases are associated with a cluster of common risk factors, including environmental factors, unhealthy diets, physical inactivity, hypertension, obesity and tobacco and alcohol use (WHO, 2017a).

Box 2.1 WHO definition of health

The World Health Organization (WHO) defines health as 'a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity' (WHO, 1948).

Major health inequities persist across Europe, with poverty associated with higher levels of disease and disability and shorter life expectancy. A 2013 report from the European Commission identifies the main causes and impacts of these health disparities, including living conditions; health-related behaviour; education, occupation and income; and healthcare, disease prevention and health-promotion services (EC, 2013c). The report acknowledges the role that exposure to air pollution can play in health inequities. In June 2018, the EU launched the Joint Action Health Equity Europe (JAHEE) project to tackle health inequalities, with the aim of achieving greater equity in health outcomes across all groups in society and reducing the inter-country heterogeneity in health inequalities (JAHEE, 2019).

Achieving the United Nation's (UN's) Sustainable Development Goals (SDGs) in Europe by 2030 will also require actions that address health inequities within and between European countries. Addressing these inequities will yield benefits for human well-being and economic prosperity, for example a 50 % reduction in inequities in life expectancy between social groups will provide monetised benefits to countries ranging from 0.3 % to 4.3 % of gross domestic product (GDP) (WHO Europe, 2019b).

Reversing health inequity is a key strategic objective of WHO Europe's European health policy — Health 2020 — which addresses the broader WHO European region (WHO Europe, 2013a). A lack of green space, poor air quality, fuel deprivation and housing deprivation are among the dimensions of living conditions that are driving health inequities in the European region (WHO Europe, 2019b). A recent report exploring environmental health inequalities in the WHO European region found an uneven distribution of exposure to environmental risks, with social deprivation associated with higher exposure. Environmental health inequities have tended to increase over time, despite an overall improvement in environmental conditions (WHO Europe, 2019a).

This chapter of the report presents evidence of the contribution that environmental stressors make to the environmental burden of disease and mortality in Europe. It introduces key indicators used to describe population health across Europe, including life expectancy, healthy life-years and the prevalence of long-standing health problems. The roles of demographic and socio-economic factors as health determinants are considered, together with the influence of socio-economic factors on the prevalence of healthy and unhealthy behaviours.

When presenting information on population health, it is useful to consider the meaning of the term 'health' in a broader context. The definition of health adopted by the WHO in 1948 is presented in Box 2.1.

More recently, commentators have proposed that health be defined as 'the ability to adapt and self-manage in the face of social, physical and emotional challenges' (Huber et al., 2011). This broader concept recognises that we cannot be healthy in an unhealthy society and that health not only encompasses physical, psychological and social aspects but is intrinsically linked to external factors, such as the health of our planetary biodiversity (The Lancet, 2009). A concept of health that includes the capacity to adapt to changing external circumstances recognises changing environmental conditions, such as climate change, as a key driver of health and well-being.

2.1 The environmental burden of disease in Europe

Environmental factors contribute significantly to the burden of death and disease in Europe and, therefore, improving environmental conditions will improve the health and well-being of European citizens. These potential benefits need to be taken into consideration during the development of future health, environment and social policies. To develop these policies, it is necessary to understand the significance of different environmental risk factors so that they can be targeted for interventions. Definitions of the different measures of the burden of disease are provided in Box 2.2.

In 2012, 13 % of deaths in the 28 EU Member States (EU-28) were attributable to the environment. These deaths could be avoided by eliminating environmental risks to health. The respective figures for the 33 member countries of the EEA (EEA-33) and the EEA-33 plus the six collaborating countries Albania, Bosnia and Herzegovina, Kosovo (under UN Security Council Resolution 1244/99), Montenegro, North Macedonia and Serbia (EEA-39) are 13 % and 14 %.

Box 2.2 Definitions of different measures of the burden of disease

The **burden of disease** is a measure of the gap between 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).

Additional deaths/excess mortality: this refers to additional deaths that are related to a specific disease. Essentially, it is the extra number of deaths due to a specific condition.

Premature deaths are deaths that occur before a person reaches an expected age. This expected age is typically the life expectancy for a country, stratified by sex. Premature deaths are considered preventable if their cause can be eliminated.

A **DALY** is 1 lost year of a '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) is defined as the years of potential life lost because of premature death. YLL is an estimate of the number of years that people in a population would have lived had there been no premature deaths. The YLL measure takes into account the age at which deaths occur and, therefore, the contribution to the total number of lost life years is higher for a premature death occurring at a younger age and lower for a premature death occurring at an older age.

Map 2.1 presents deaths attributable to the environment, by country, for the EEA-39 excluding Liechtenstein and Kosovo. There is a clear discrepancy between countries in the east of Europe and in the west of Europe, with the highest fraction of national deaths (27 %) attributable to the environment in Bosnia and Herzegovina and the lowest in Iceland and Norway (9 %). In terms of EU countries, the highest environmental contribution to mortality is seen in Romania (19 %), while the lowest is seen in Denmark and Sweden (10 %) (WHO, 2016a).

In terms of the absolute number of deaths attributable to the environment, in the EU-28, 630 000 deaths were attributed to the environment in 2012. The figures for the EEA-33 and the EEA-39 are 716 000 deaths and 755 000 deaths, respectively (WHO, 2016a).

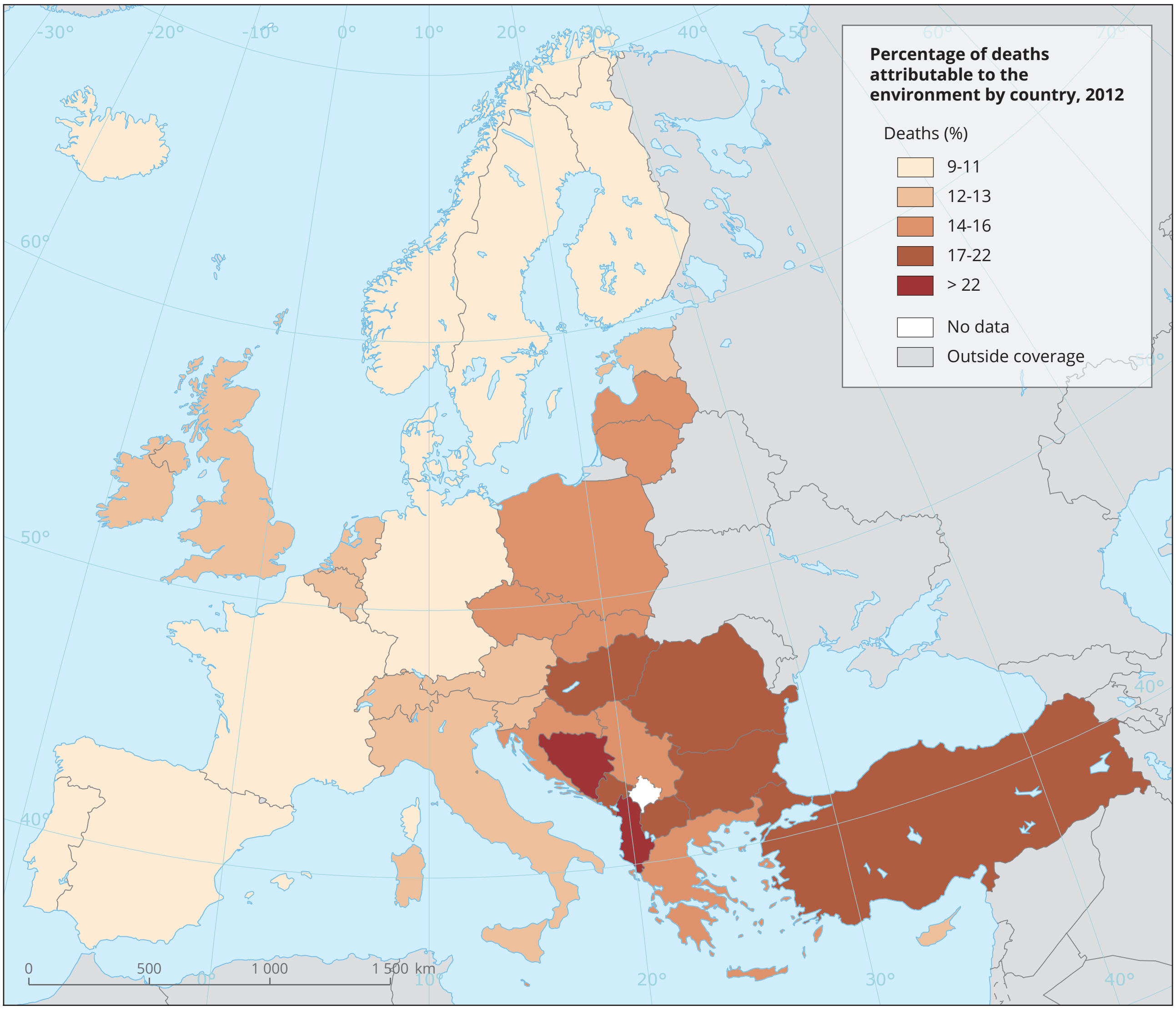
Looking at individual countries, the same differences between eastern Europe and western Europe can be seen. Figure 2.1 presents the number of deaths attributable to the environment per 100 000 of the population in the EEA-39 for the year 2012, adjusted for differences in the age distribution of the various populations. Such deaths could be prevented by eliminating environmental risks to health. The numbers vary significantly, from a high of 172 per 100 000 in Albania to a low of 35 per 100 000 in Iceland. In terms of EU countries, Romania has the highest number of deaths per 100 000 attributable to the environment, while Sweden has the lowest number. The higher burden of deaths from environmental conditions in the east of Europe is clearly visible, with the more recent members of the EU consistently showing higher numbers of deaths per 100 000, with the exception of Cyprus, Estonia and Slovenia. All EU countries with a burden of preventable deaths attributable to the environment greater than 15 % have joined the EU since 2004, with the sole exception of Greece.

Data on deaths attributable to the environment are taken from the WHO's Global Health Observatory data repository, based on the study 'Preventing disease through healthy environments' (Prüss-Ustün et al., 2016). The aspects of the environment that drive deaths included in the methodology are:

- air, soil and water pollution with chemicals or biological agents;
- noise and electromagnetic fields;
- anthropogenic climate change and ecosystem degradation;
- ultraviolet and ionising radiation;
- the built environment;
- occupational risks;
- agricultural methods and irrigation schemes;
- individual behaviours related to the environment, such as hand washing, food contamination with unsafe water and dirty hands.

As a result, the scope goes beyond the dimensions of environmental quality addressed in this report to include occupational risks, the built environment,

Map 2.1 **Percentage of deaths attributable to the environment by country (EEA-39 excluding Liechtenstein and Kosovo), 2012**



Note: No data are available for Liechtenstein or Kosovo.

Source: WHO (2016a).

ultraviolet radiation, agricultural practice and sanitary behaviours. Nevertheless, the majority of the stressors are covered in this report to a greater or lesser extent.

In Europe, 90 % of deaths attributable to the environment result from non-communicable diseases, including cancers, cardiovascular diseases, mental, behavioural and neurological disorders, musculoskeletal disorders and asthma. This is consistent across the EU 28, the EEA-33 and the EEA-39 (WHO, 2016b). Figure 2.2 identifies the top 10 non-communicable diseases causing deaths attributable to the environment in high-income European countries in 2016. Cancers are the number one cause of death, followed by ischaemic heart disease, chronic obstructive pulmonary disease and stroke.

In 2016, environmental factors lay behind 39 % of disability adjusted life years (DALYs) resulting from lung cancer amongst men and 21 % amongst women in high income countries ([2]). For other cancers the fraction of DALYs attributable to the environment are 16 % for men and 13 % for women. Regarding ischaemic heart

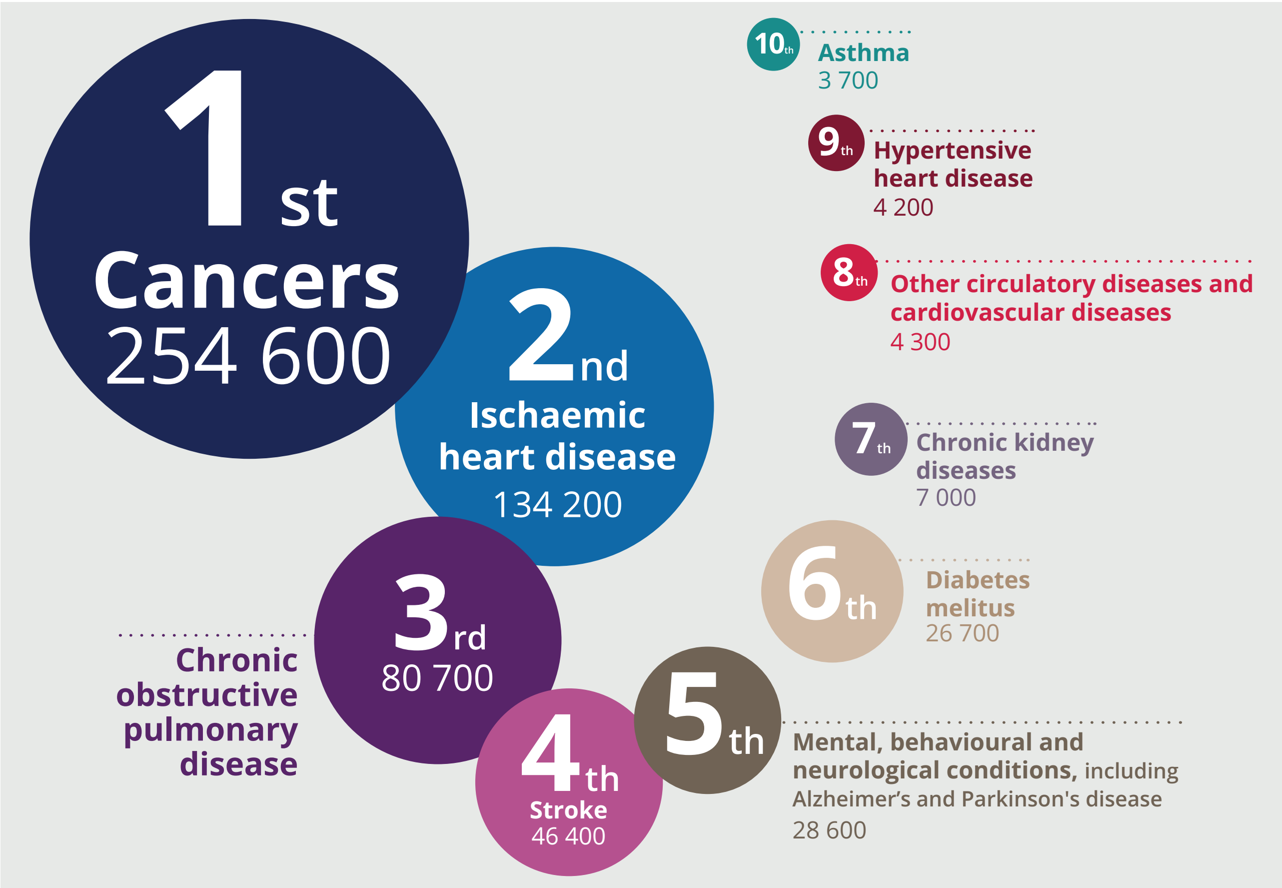
([2]) High income countries as defined by the WHO.

Figure 2.1 **Age-standardised deaths attributable to the environment in the EEA-39 countries, per 100 000 people, 2012**

Note: No data are available for Liechtenstein or Kosovo.

Source: WHO Global Health Observatory Data Repository.

Figure 2.2 Top 10 non-communicable diseases causing deaths attributable to the environment in the high income European countries, 2012



Note: The high-income countries in Europe include Andorra, Austria, Belgium, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia, Lithuania, Luxembourg, Malta, Monaco, the Netherlands, Norway, Poland, Portugal, San Marino, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

Source: WHO (2016b).

disease, 16 % of associated DALYs were attributable to the environment in 2016, while the figures for chronic obstructive pulmonary disease and stroke are 29 % and 12 % respectively (Prüss-Üstün, 2019).

Exposure to environmental pollution reduces quality of life, as people live with associated health conditions such as asthma, heart disease and cancer. The number of healthy life-years that are lost in the EU-28 countries as a result of environmental pollution is estimated at more than 20 million annually, rising to over 25 million for the EEA-39 countries, based on WHO data for 2012 (WHO, 2016c).

In terms of which environmental stressors drive disease, Table 2.1 identifies linkages between a range of non-communicable diseases and environmental risk factors addressed in this report (Prüss-Ustün et al., 2016). It is worth noting that a number of environmental risk factors contribute to the same diseases. For example, air pollution, noise, chemicals and climate change all contribute to the burden of cardiovascular disease, while noise, chemicals and climate change all drive neuropsychiatric disorders. By acquiring a better understanding of the contribution of environmental risk factors to disease, future environmental policies can be directed towards delivering the best health outcomes for the citizens of Europe.

Table 2.2 provides an overview of estimates of the burden of death and disease associated with exposure to different environmental stressors. Air pollution has the most significant impact on health, leading to around 400 000 premature deaths per year and nearly 4 million DALYs in the EU. Noise comes second, driving over 12 000 premature deaths per year and over 1 million DALYs in the EEA-33.

Table 2.1 Summary of indicative links between non-communicable diseases and related environmental risk factors

Disease	Environmental risk factors: Ambient air pollution	Noise	Chemicals	Climate change	Indoor fuel combustion	Radiation
Cancers	△		△		△	△
Neuropsychiatric disorders		△	△	△		
Cataracts					△	△
Hearing loss		△				
Cardiovascular disease	▲	△	△	△	▲	
Chronic obstructive pulmonary disease	△				▲	
Asthma	△				▲	
Chronic kidney disease			△			
Skin diseases			△			
Congenital anomalies	△		△			△

Population attributable fractions △ < 5 % ▲ 5–25 %

Notes: The population attributable fractions are presented as follows: △ = < 5 %, ▲ = 5-25 %. These are based on global estimates, rather than Europe-specific data. Chemical risk factors are limited to industrial and agricultural chemicals, including those involved in acute poisoning. The source report for the data above (Prüss-Ustün et al., 2016) covers a broader range of environmental risk factors than that included in this table. The indoor fuel combustion data should be considered with caution from a European perspective, as this relates to exposure to pollutants due to indoor solid fuel use for cooking, which is not common in most European countries but is a factor for some EEA cooperating countries.

Source: Adapted from Prüss-Ustün et al. (2016).

Estimates of the DALYs attributable to indoor air pollution range from 300 500 to 2 million at the EU level, with the lower estimate based on emissions from solid fuels used for cooking and the higher capturing a broader range of air pollutants and radon.

Regarding the impacts of climate change on health, data are scarcer because of the complexity of attributing single weather events to climate change and the manner in which climate stressors interact with a broad range of social factors to bring about an impact on health. Heatwaves are the deadliest type of extreme weather across Europe as a whole, with 70 000 deaths attributed to the heatwave of 2003 (Robine et al., 2008). Over the period 1980-2017, 90 325 deaths resulted from the impacts of extreme weather and climate-related events in the EEA-33. In economic terms, in the EU Member States, disasters caused by weather and climate-related extremes accounted for some 83 % of monetary losses caused by natural hazards over the period 1980-2017, equating to EUR 426 billion (at 2017 values) (EEA, 2019b).

For chemicals, data are not available because of the sheer complexity of establishing causality for the large number of chemical pollutants and attributing disease fractions. The World Health Organization attributes 2.7 % of all global deaths in 2016 to exposure to a relatively limited number of chemicals (WHO, 2018c).

This burden of death and disease could be avoided by eliminating environmental pollution and degradation. It signals an urgent need to improve environmental conditions, particularly in the east of Europe, to reduce the burden of disease and mortality and improve quality of life.

2.2 Health indicators for Europe

Health is multifaceted, and no single indicator is able to fully describe the health status of a population or the influence that health has on an individual's quality of life. As a result, multiple health indicators are relied on

Table 2.2 Estimates of the health impacts of different environmental stressors

Stressor	Premature deaths per year		Total annual DALYs		Additional deaths/excess mortality	
Air quality	Particulate matter ($PM_{2.5}$) ([a])		Particulate matter ([b])		Particulate matter ([b])	
	EU-28:	379 000	EU-28:	3 953 042	EU-28:	225 554
			EEA-33:	4 937 395	EEA-33:	265 410
	EEA-39:	417 000	EEA-39	5 217 479	EEA-39:	278 845
	Nitrogen dioxide (NO_2) ([a])					
	EU-28:	54 000				
	EEA-39:	55 000				
	Ozone (O_3) ([a])					
	EU-28:	19 400				
	EEA-39:	20 600				
Noise ([c])	EU-28:	11 702	EU-28:	1 013 592	No data	
	EEA-33:	12 014	EEA-33:	1 046 075		
Indoor air quality	No data		EU-28 ([d]):	300 518	EU-28 ([d]):	14 659
			EEA-33 ([d]):	300 518	EEA-33 ([d]):	14 659
			EEA-39 ([d]):	538 944	EEA-39 ([d]):	25 653
			EU-26 ([e]):	2 000 000		
Extreme weather and climate-related events ([f])	No data		No data		90 325 deaths in EEA-33 over the period 1980-2017 ([f])	
Heatwaves	No data		No data		77 637 deaths attributed to heatwaves over the period 2010-2017 ([f]) 70 000 deaths in the heatwave of 2003 ([g])	
Floods ([h])	No data		No data		8 000 deaths in the EEA-33 over the period 1980-2016 ([h])	
Chemicals ([i])	No data		1.7 % of total DALYs globally ([i])		2.7 % of total deaths globally ([i])	

Notes: ([a]) Based on 2018 data; figures for $PM_{2.5}$ and NO_2 rounded to the nearest thousand and for O_3 to the nearest hundred; EEA-39 excluding Turkey; EEA (forthcoming).

([b]) Based on 2016 data; EEA-33 excluding Liechtenstein and EEA-39 excluding Liechtenstein and Kosovo; WHO (2018a).

([c]) Based on 2017 data; EEA-33 excluding Turkey; EEA (2020a).

([d]) Based on 2016 data; relates to only solid fuel used for cooking; data for the EEA-33 exclude data for Liechtenstein and Turkey and data for the EEA-39 exclude data for Kosovo, Liechtenstein and Turkey; WHO (2018b).

([e]) EU-26 results are for the EU-28 excluding Malta and Croatia, based on 2010 data, and include the contribution of $PM_{2.5}$ from outdoor air pollution as well as other indoor factors such as radon, dampness and VOCs; Asikainen et al. (2016).

([f]) EEA (2019b).

([g]) Robine et al. (2008).

([h]) EEA (2017a).

([i]) Data for 2016; WHO (2018c).

$PM_{2.5}$, particulate matter with a diameter of 2.5 μm or less; VOC, volatile organic compound.

to understand population health. Figure 2.3 presents the status of a number of important health indicators in Europe, including life expectancy at birth, healthy life-years, self-perceived health and the percentage of the population with a long-standing health problem.

Healthy life-years are defined as the number of years a person is expected to live in a healthy condition and are based on an individual's self-declared ability to live without limitations in their daily functioning. This is based on the perception that individuals have of their own health. While variations between and within EU Member States might reflect objective differences in actual health, they may also reflect differences between population attitudes or individual attitudes towards health. In 2017, the number of healthy life years at birth was estimated at 64 years for women and 63.5 years for men in the EU-28; this represented approximately 77 % and 81 % of the total life expectancy for women and men (Eurostat, 2020a).

It is of note that the trend of a steady increase in life expectancy in the EU from 2001 to 2011 slowed considerably in many Member States in the years up until 2016 because of a slower rate in the reduction of cardiovascular disease and an increase in the number of deaths among the elderly during the winter months (OECD and EU, 2018).

2.3 Changing demographics in Europe

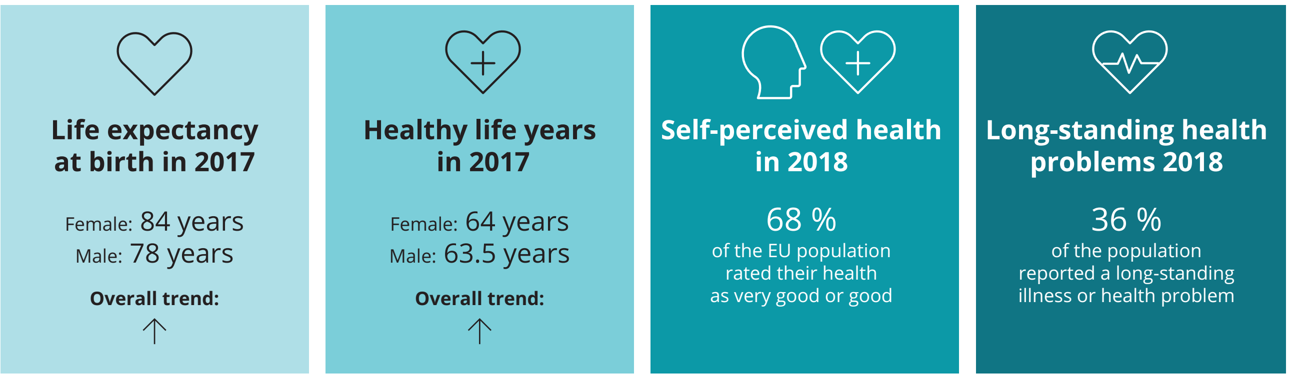
Demographic changes in Europe pose key economic and social challenges. These challenges are linked to the healthcare burden but also have implications for environmental health. Three key demographic factors influence the health of the European population: the ageing population, migration and a high proportion of the European population living in urban areas. This section presents a brief overview of these three demographic factors, briefly reflecting on the links to the environment and health.

2.3.1 The ageing population

The EU-28 is home to 511.8 million inhabitants. Although the population of some Member States is declining and the overall rate of population growth has slowed in recent decades, the population of the EU-28 as a whole continues to grow and is expected to peak at around 529 million people by 2045 (Eurostat, 2017a).

In 2018, 19.7 % of the EU population was over 65 years old (Eurostat, 2019c). More than half of EU citizens aged 65 to 74 report a long-standing illness or health problem. Aside from Japan, the EU has the world's most rapidly ageing population (Eurostat, 2017a). This has been

Figure 2.3 Summary of key indicators of health across Europe

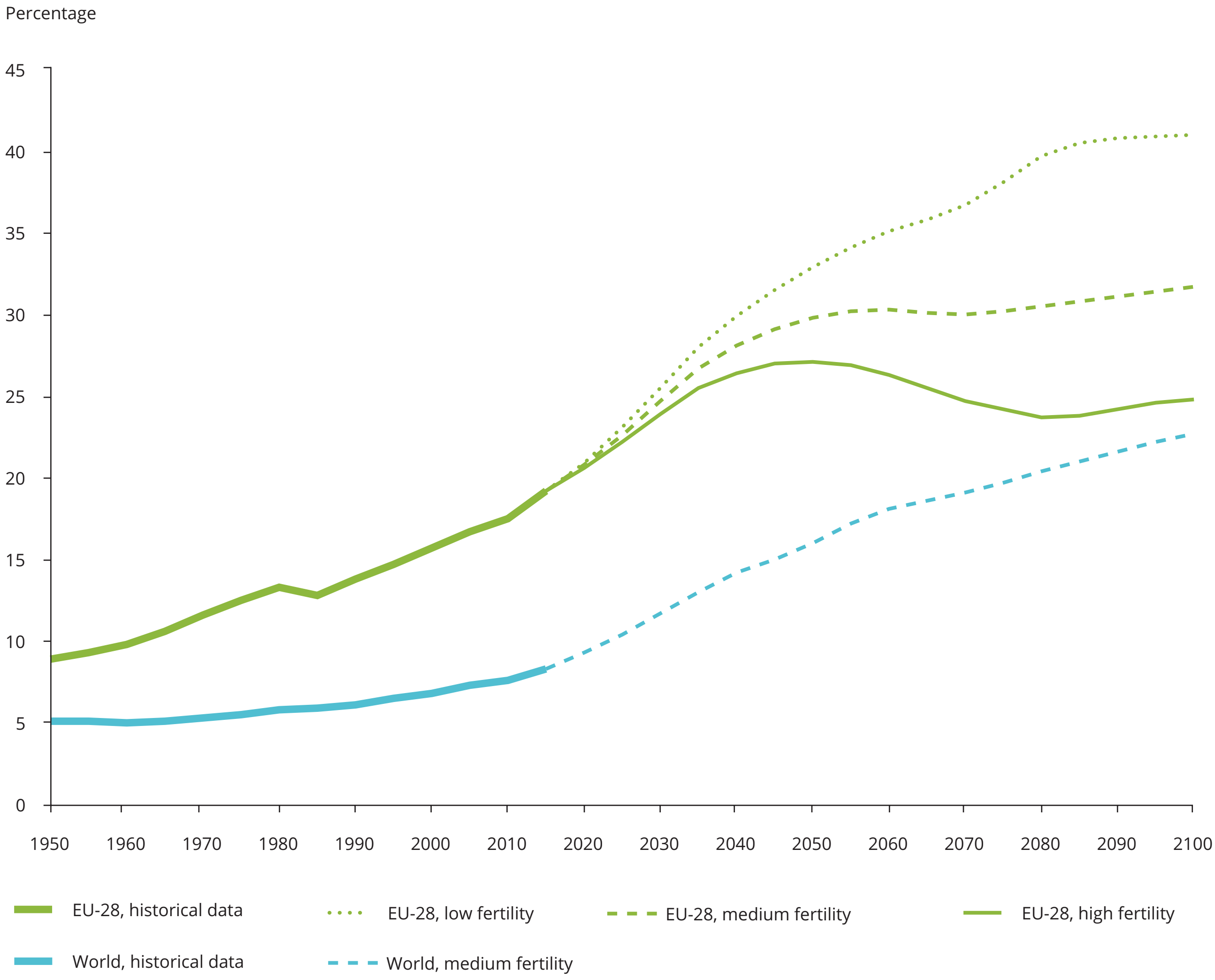


Sources: Eurostat (2019b, 2020a, 2020b).

Links between aging and environmental health

Older people are more susceptible to the effects of environmental stressors such as pollution, climate change impacts, for example heatwaves, and water pollution. They are also less resilient, with a lower capacity to recover from negative health impacts, restore damage to their homes and avoid future risks. As the population ages, a higher proportion will be at risk of being negatively affected by environmental pollution and climate change. Access to green space in urban areas can reduce the social isolation of older people. The accessibility of green and blue spaces needs to be considered as the ageing population becomes less mobile.

Figure 2.4 Historical and projected share of people over 65 in Europe and worldwide



Source: EEA (2016a).

described as a 'demographic time-bomb' (EC, 2005), as demands for social welfare and healthcare provisions are increasing while the share of the population that is of working age is declining. Figure 2.4 presents the historical and projected share of people aged 65 and over in the EU-28 and worldwide, showing how low fertility rates may lead to as much as 40 % of the EU population being over 65 by the year 2100.

2.3.2 Urbanisation

Ongoing urbanisation — referring to the growth in the number of people who live in urban areas — is another key trend in Europe (EuroHealthNet, 2017). The level of urbanisation in Europe is expected to increase from 74 % at present to about 75 % in 2020 and 83.7 % in 2050 (UN DESA, 2018). This requires effective urban planning, to limit the potential adverse health implications and inequalities that can result from urban living (WHO Europe, 2017b).

Hazards for urban populations include increased exposure to air pollution, noise levels, waste and the heat island effect during high temperatures, as well as increased sedentary behaviour and isolation. These factors contribute to the growing epidemic of non-communicable diseases and mental health issues (Carmichael et al., 2017).

In addition, people living in EU cities are more likely to suffer from chronic depression. For example, in 2014 7.8 % of people living in cities in the EU-28 reported suffering from depression, compared with 6.2 % in rural areas. However, this pattern was not the same in all parts of Europe, with countries such as Croatia, Hungary, Spain and Sweden reporting higher levels of depression in rural areas (Eurostat, 2018a).

The provision of well-designed urban environments also provides the potential to create positive health and well-being opportunities, while the proximity of people, businesses and services also allows for the development of a more resource-efficient Europe. Well-designed cities and urban areas can also, for example, provide shorter journeys to work, more opportunities to walk, cycle and use public transport, and more access to urban green and blue spaces.

2.3.3 Migration

Immigration is the primary driver of population growth in Europe. From 2012 to 2016, positive net migration into Europe accounted for 80 % of population growth, and this trend is set to continue (Eurostat, 2017a). Immigration not only occurs between Member States but also stems from non-EU countries. In 2016, the number of non-EU citizens entering the EU was 1.3 million, and the non-EU population reached almost 22 million. These population flows have the potential to create additional strains on healthcare systems, which in some cases must cater for rapid localised population growth. However, the younger age profile of the migrant population counters the effect of the ageing population.

2.4 The influence of socio-economic factors on health

The relationship between socio-economic status and health inequality is unequivocal (Pickett and Wilkinson, 2015). Societies with wide disparities in socio-economic status also have wide disparities in health outcomes. These disparities are influenced by differences in social protection, education, income, access to healthcare, disease prevention and living conditions (EC, 2013c).

There are also relationships between health risk factors, such as tobacco use, and socio-economic circumstances (EC, 2013c). Within the EU, populations with higher levels of education and wealth generally perceive their own health status as good and show improved life expectancy. However, populations that are less educated and poorer perceive their own health status as bad and have a lower life expectancy. Across the EU, people with a low level of education can expect to live 6 years less than those with a high level of education (OECD and EC, 2018).

A study of 16 European cities found evidence of a consistent pattern of inequality in mortality, with mortality increasing in parallel with socio-economic deprivation (Borrell et al., 2014). Nearly half of excess mortality in the lower socio-economic groups is explained by inequalities in cardiovascular diseases (Dahlgren and Whitehead, 2006), for which environmental conditions, such as air pollution and opportunities for physical activity, are key risk factors (WHO Europe, 2017b). Recent reviews at European level have demonstrated a consistent link between social deprivation and exposure to environments of poorer quality across Europe (EEA, 2018a; WHO Europe, 2019a). The relationship between exposure and vulnerability to environmental stressors and socio-economic status is examined for specific stressors in Chapter 4.

The sections below briefly examine the influence of various socio-economic factors on health.

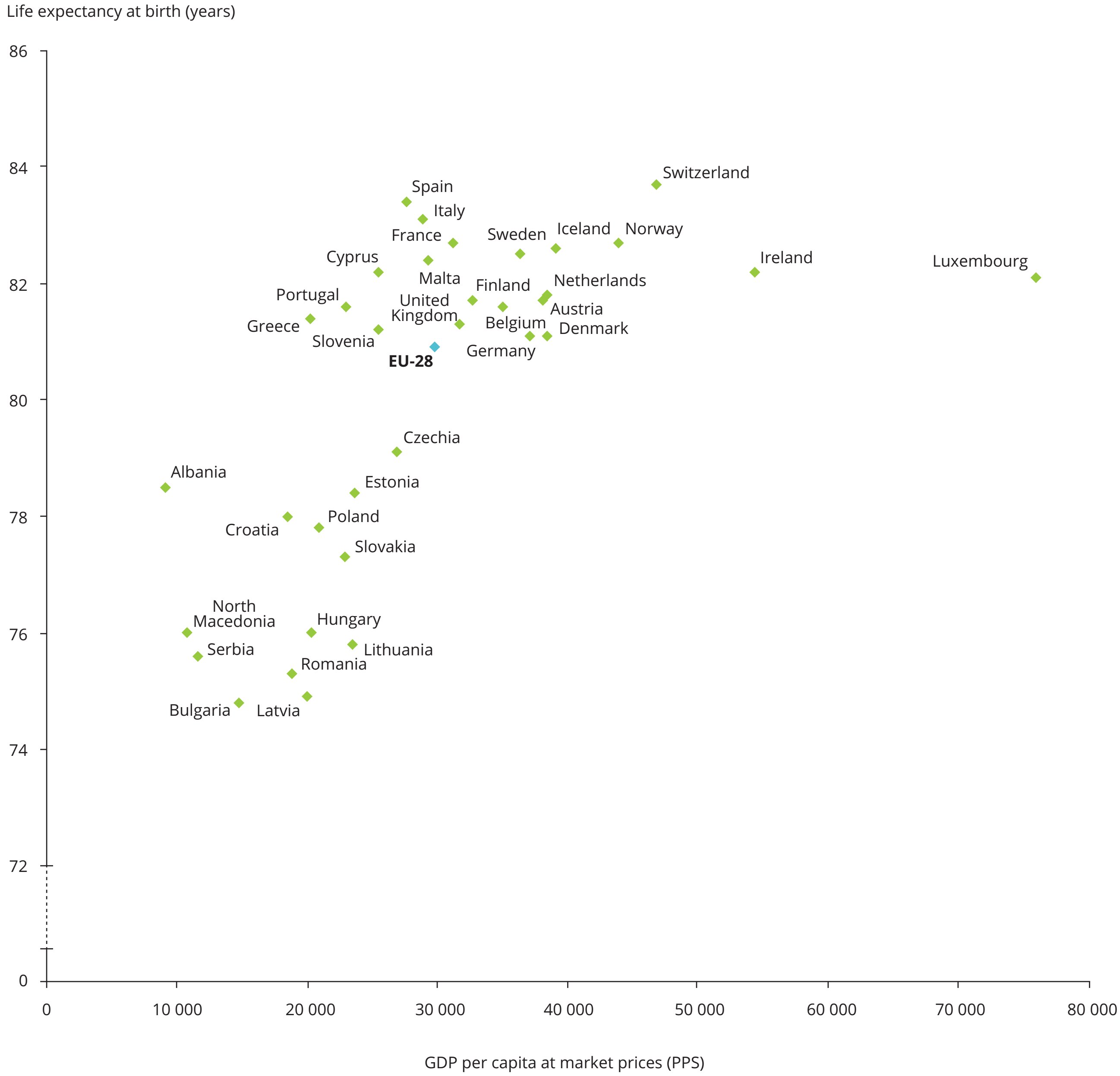
Links between urbanisation and environmental health

Urban environments see a concentration of stressors such as air pollution, noise, heat and chemical exposure. An increasing proportion of the future population will be at risk of being negatively affected by these environmental stressors unless appropriate urban design and planning principles are applied and efforts are made to address sources of pollution, such as unsustainable transport.

Links between migration and environmental health

Migrants from outside the EU, and even their children who are born within the EU, are at a greater risk of being socio-economically disadvantaged (OECD, 2017) and thus potentially live in areas with, for example, higher levels of traffic, sub-standard housing and poor access to green spaces. They are therefore more likely to be exposed to environmental stressors, such as poor indoor air quality, heat and cold stress, noise and air pollution. Urban green spaces provide an arena for immigrant communities to interact with other people from the local community, promoting integration and social cohesion.

Figure 2.5 Life expectancy at birth and GDP per capita, 2017



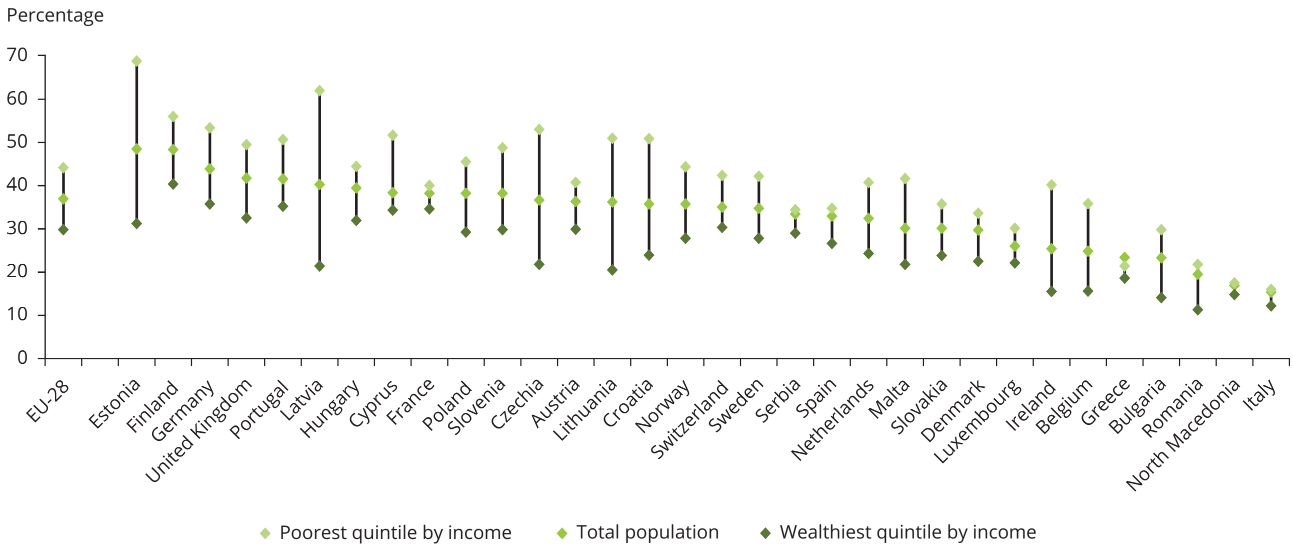
Note: GDP per capita is expressed in units of purchasing power standard (PPS) — this is a notional common currency that eliminates the differences in price levels, allowing meaningful volume comparisons of GDP between countries. Data for North Macedonia and the United Kingdom are for 2016.

Source: Eurostat (2019b).

2.4.1 The relationship between socio-economic status and life expectancy

Life expectancy at birth in 2017 ranged from 74.8 years in Bulgaria to 83.1 years in Italy — a difference of 8.3 years. The economic status of an individual Member State has an effect on life expectancy, as shown in Figure 2.5, which shows the relationship between life expectancy at birth and GDP per capita. Three main European groups are identifiable: the Baltic and eastern European Member States, which exhibit a relatively low life expectancy at birth and low levels of GDP; Mediterranean Member States, which generally have a relatively high life expectancy and medium GDP per capita; and western European and Nordic Member States, where life expectancy is generally similar to that in Mediterranean Member States, but GDP is higher.

Figure 2.6 **Percentage of the population suffering from a long-standing illness or health problem, by income situation, 2018**



Note: Ranked on the share of the total population suffering from a long-standing illness or health problem. A quintile is a statistical value that represents 20 % of a given population. Data is provided for the proportion of the population aged 16 and over. No data was available for Albania, Bosnia and Herzegovina, Iceland, Kosovo, Lichtenstein, Montenegro and Turkey.

Source: Eurostat (2020b).

2.4.2 The relationship between socio-economic status and the risk of having a long-standing health problem or disease

A long-standing health problem or disease is a health problem that has lasted, or is likely to last, at least 6 months. Over one third of the EU-28 population reported that they suffered from a chronic condition in 2018. As Figure 2.6 indicates, inequalities exist in health, based on income. Overall in the EU, 31 % of people in countries in the top income quintile (i.e. the wealthiest) reported having a long-standing illness or health problem, compared with 44 % in the bottom quintile (i.e. the poorest) (Eurostat, 2020b).

2.4.3 The relationship between socio-economic status and self-perceived health

In terms of self-perceived health, 68 % of people aged 16 and over in the EU declared themselves to be in 'good' or 'very good' health in 2018 (see Figure 2.7). In all EU Member States the share of men perceiving their health as good or very good is higher than the share of women. The share of both men and women perceiving their health as good or very good increases with level of education and with income. In the top income quintile of the population (i.e. the wealthiest) 79 % rated their health as very good or good, while in the bottom quintile (i.e. the poorest) 59 % rated their health as very good or good (Eurostat, 2020b).

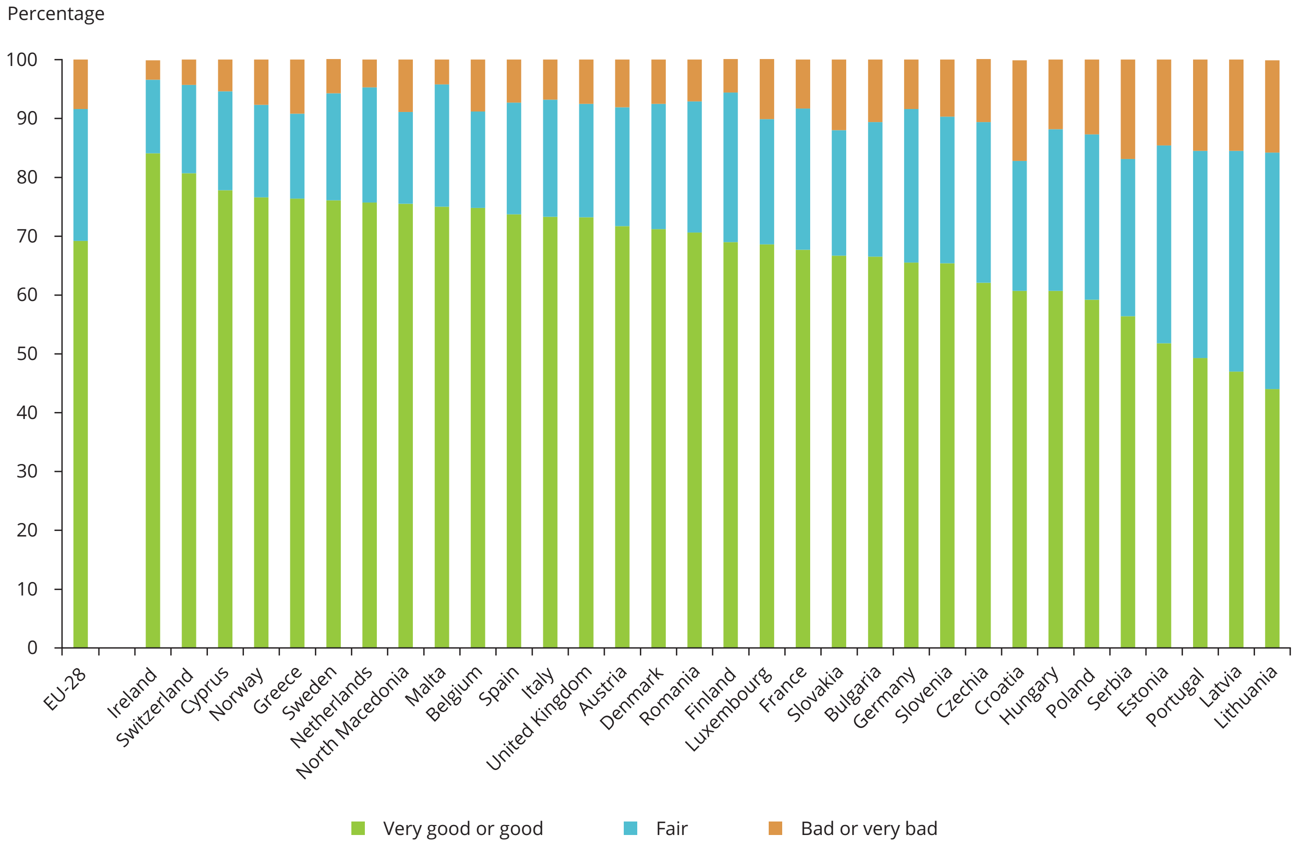
As would be expected, self-perceived health tends to deteriorate with age. In 2018, fewer people rated their health as being very good or good in higher age groups than in lower age groups, while the share reporting bad or very bad health increased with age.

The VulnerABLE project supported efforts to improve the health of the most vulnerable social groups and is described in Box 2.3.

2.5 Healthy and unhealthy behaviours

The prevalence of health-related behaviours, such as those related to diet, physical activity and smoking, are useful indicators of a population's health because of their association with non-communicable chronic diseases (Forouzanfar et al., 2015). Targeting these behaviours can improve the health of a population. The brief analysis of a number of factors presented in Figure 2.8 highlights their significant influence on health in Europe and also indicates that they are influenced by socio-economic status. For example, Figure 2.9 indicates how the percentage of the population that spent time on health-enhancing physical activity varies by level of education, with a lower proportion of less educated groups engaging in exercise that benefits health. Research is now focused on the linkages between behaviour, health and environmental sustainability, with examples provided in Box 2.4.

Figure 2.7 Percentage of the population by perceived health status, 2018



Note: Ranked on the share of the total population rating their health as 'good' or 'very good'. Data is provided for the proportion of the population aged 16 and over. No data was available for Albania, Bosnia and Herzegovina, Iceland, Kosovo, Lichtenstein, Montenegro and Turkey.

Source: Eurostat (2020b).

Box 2.3 VulnerABLE pilot project

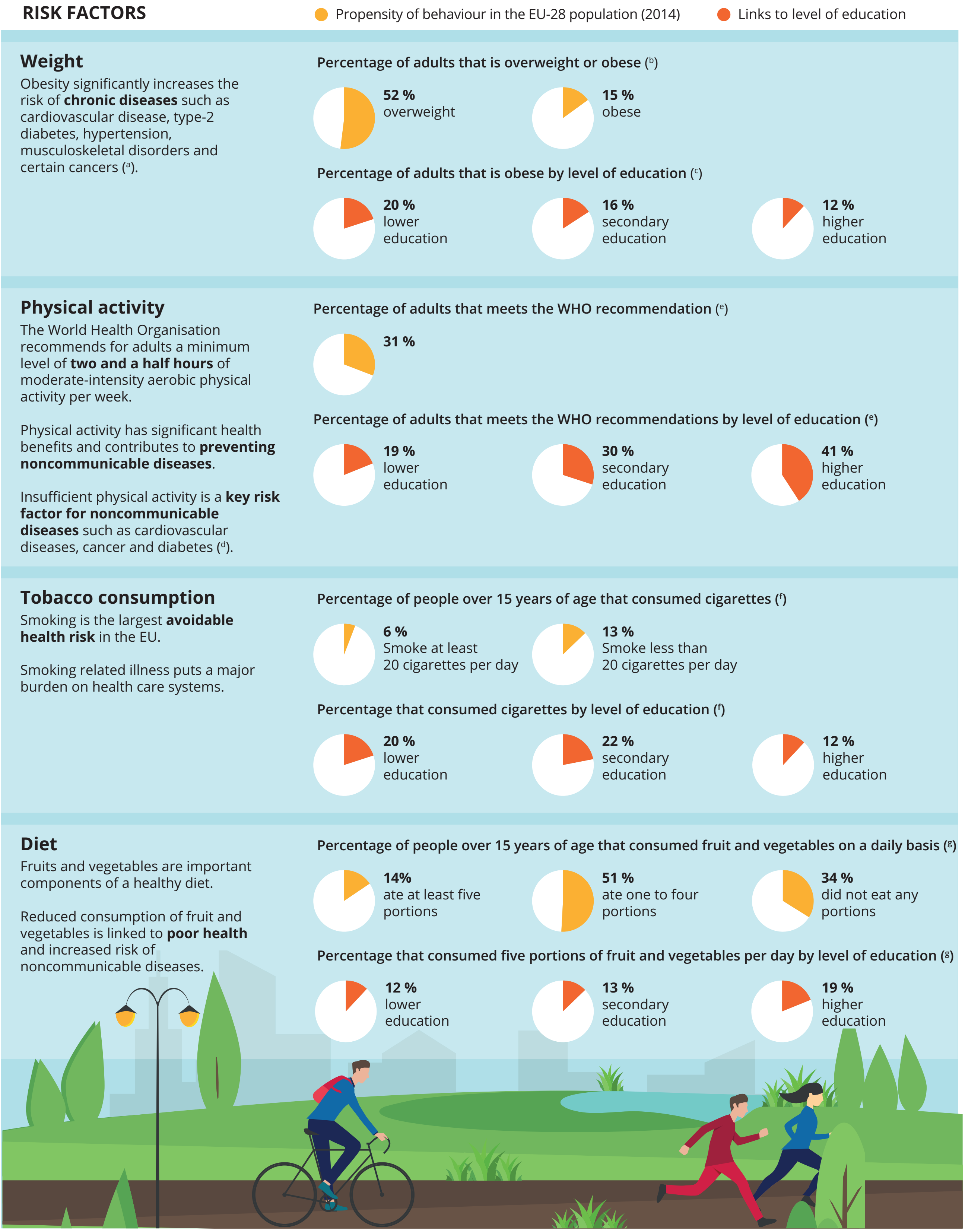
The VulnerABLE project was an initiative of the European Commission that aimed to increase understanding of how best to improve the health of people living in vulnerable and isolated situations, to identify and recommend evidence-based policy strategies and raise awareness of the findings, and to support capacity building within Member States.

Implemented between 2015 and 2017, the focus was on nine specific vulnerable and isolated populations, namely (1) children and families from disadvantaged backgrounds, (2) those living in rural/isolated areas with physical disabilities or poor mental health, (3) the long-term unemployed, (4) inactive people, (5) those from lower income brackets, (6) the elderly, (7) victims of domestic violence and intimate partner violence, (8) the homeless and (9) prisoners.

The project produced criteria for effective policy approaches to improving the health of and access to healthcare for people living in vulnerable and isolated situations.

Source: EC (2017a).

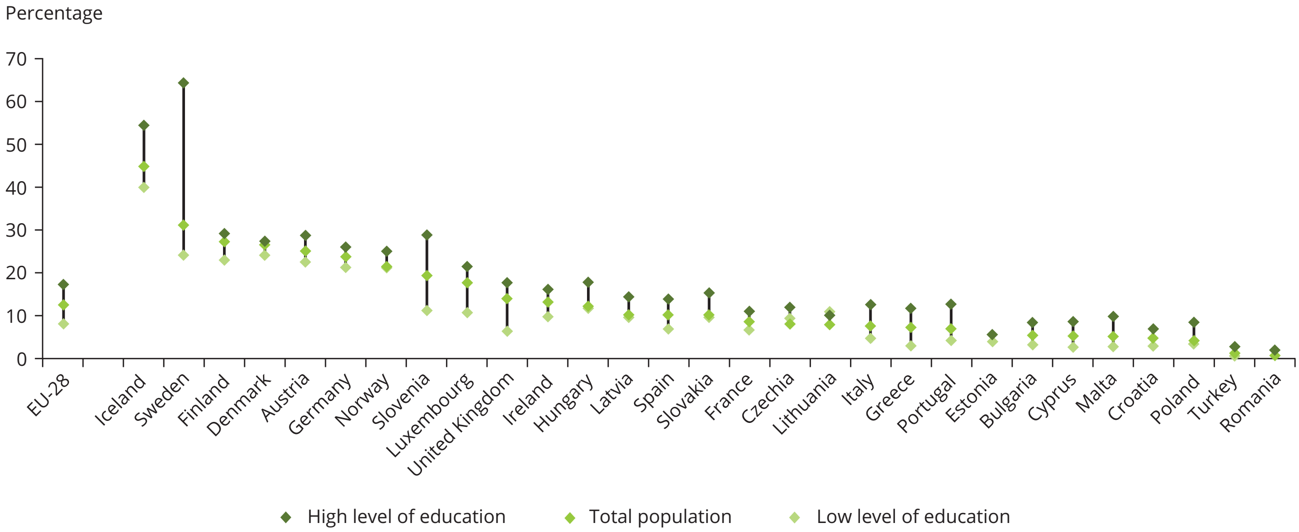
Figure 2.8 Summary of factors associated with healthy and unhealthy behaviours



Note: Obesity and overweight: An adult is considered overweight if she or he has a body mass index greater than or equal to 25. Obesity is the condition of severe overweight where an adult has a body mass index equal to or greater than 30. The consideration of obesity as a behavioural issue should be treated with some caution, as genetic factors can result in an inherited predisposition to obesity.

Sources: (a) WHO (2018d); (b) Eurostat (2020c); (c) Eurostat (2019b); (d) WHO (2018e); (e) Eurostat (2018b); (f) Eurostat (2020d); (g) Eurostat (2018c).

Figure 2.9 **Percentage of the population aged 18 and over that did health-enhancing aerobic and muscle strengthening exercise, by level of education in 2014**



Source: Eurostat, 2018b.

Box 2.4 **Supporting behavioural change**

Addressing unhealthy behaviours in a comprehensive and effective way is a major public health challenge for European countries and has been addressed by a number of European research projects, including the following:

Inherit — this Horizon 2020 project explores how people can be encouraged to adopt behaviours that contribute to better health, reduced health inequalities and environmental sustainability (Inherit, 2019a). The project includes a database of good practice case studies from around Europe, on the topics of 'living' (green space, housing), 'moving' (active transport) and 'consuming' (food). The database is publicly accessible at: https://www.inherit.eu/db-results.

PASTA — this EU-funded project reviewed how urban planners can create urban environments that encourage healthy behaviour and physical activity (PASTA, 2019). The project developed a health economic assessment tool (HEAT), which allows the quantitative assessment of measures to promote active mobility. The project website is available at: https://pastaproject.eu/home.

3 The benefits of nature for health and well-being

Quality 'green' and 'blue' spaces in urban environments deliver a triple win, offering benefits for health, society and the environment. Improving access to high-quality green and blue spaces offers opportunities to improve health outcomes for urban populations.

The benefits for health and well-being depend on an individual's interaction with the space, which is influenced by both the characteristics of the space, such as access, quality and safety, and personal choices and capacities. The accessibility of green and blue spaces to different social groups determines how benefits are distributed across society. The presence of green space in a local neighbourhood is especially important for socially deprived populations, children and the elderly.

Box 3.1 Defining green and blue spaces

Green space: an area of vegetated land within the urban fabric, predominantly designed for recreational use. These can be natural areas of different scales, from green roofs or pocket gardens to large urban parks.

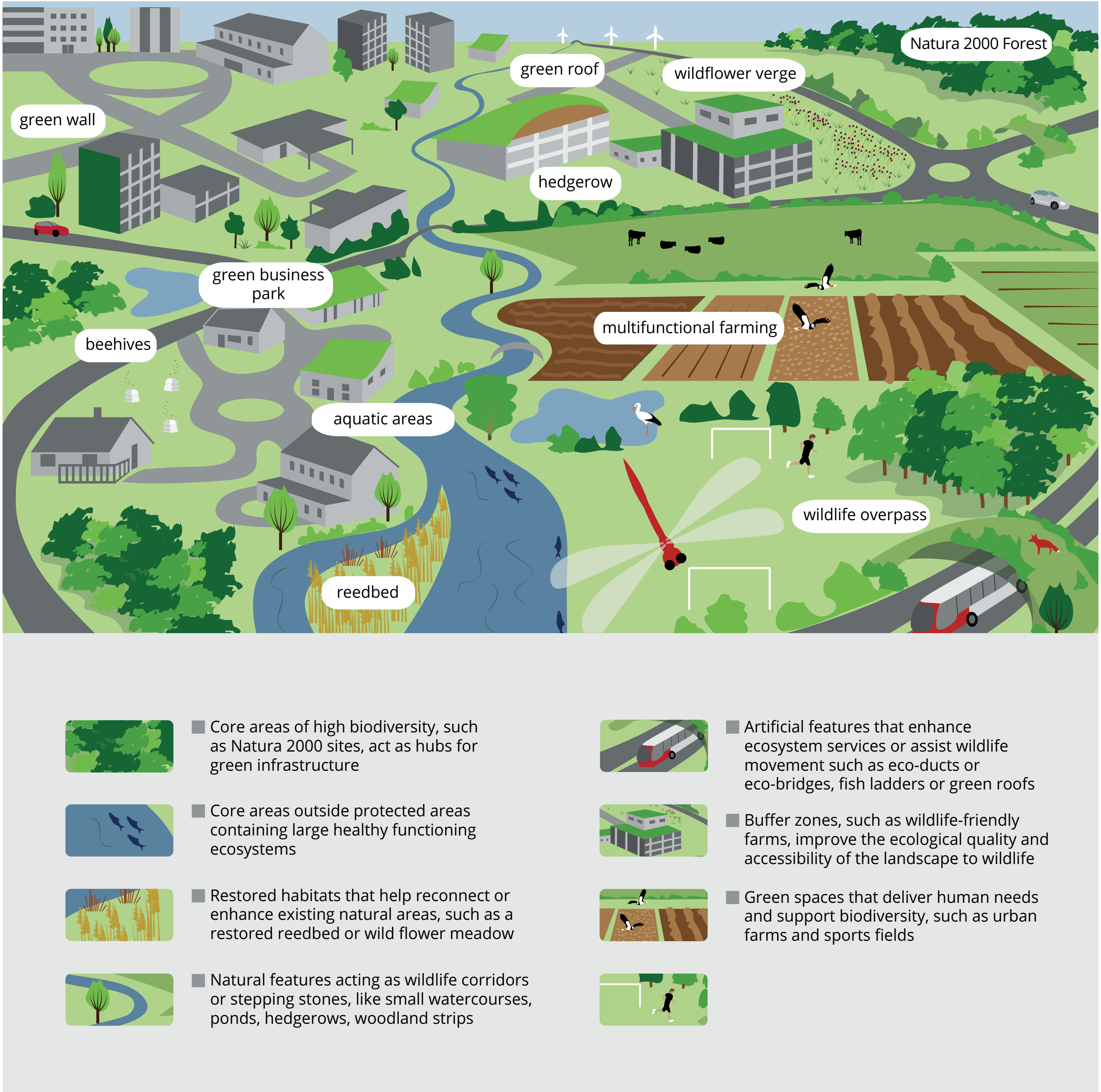
Blue space: spaces with water as the main focus, either marine water or freshwater.

Green infrastructure: a strategically planned network of natural and semi-natural areas designed and managed to deliver ecosystem services. In urban areas, features may include parks, gardens, grassy verges, green walls and green roofs, as well as aquatic elements, as long as they are part of an interconnected network.

The photo below shows an example of a public blue space in Copenhagen, Denmark.

Photo: © EEA.

Figure 3.1 Types of green infrastructure in urban areas



Source: EC (2013d).

Green and blue spaces can mitigate environmental stressors in the immediate term, for example by alleviating air pollution, providing cool spaces during periods of heat and reducing noise, as well as increasing ecosystem resilience and enhancing carbon storage over the longer term. This is particularly relevant for green spaces in urban areas.

Definitions of green and blue spaces, as well as the broader concept of green infrastructure, are provided in Box 3.1, while various types of green infrastructure in urban areas are shown in Figure 3.1.

Recognition of the potential benefits of urban green and blue spaces is driving an increasing interest in nature-based solutions as a means of ensuring the delivery of ecosystem services and reversing biodiversity loss. Box 3.2 identifies EU policies and initiatives that protect and promote green and blue spaces.

This chapter explores the evidence for health, social and environmental benefits from these spaces, with a focus on green spaces in urban areas. It also examines how access to green spaces varies, both

Box 3.2 EU policies and initiatives to promote green spaces

The EU Biodiversity Strategy for 2030 identifies nature as central to human well-being and social resilience and foresees a key role for nature-based solutions in tackling climate change (EC, 2020c). It calls for the development of ambitious Urban Greening Plans for European cities by the end of 2021, including measures to create biodiverse and accessible urban forests, parks and gardens; urban farms; green roofs and walls; treelined streets; urban meadows; and urban hedges.

These strategy areas are supported by EU guidance for the deployment of EU-level green and blue infrastructure through policy, planning and business investment decisions (EC, 2019b). Complementary guidance defines criteria for green and blue infrastructure, and identifies available technical and financial support instruments that can help planners integrate natural landscape features into strategic 'green and blue infrastructure' (EC, 2019c).

A number of other EU initiatives promote access to green spaces in urban areas:

- Priority objective 8 of the Seventh Environment Action Programme is entitled '**Sustainable cities, working together for common solutions**' (EU, 2013a).
- The **urban agenda for the EU** promotes cooperation between Member States, cities, the European Commission and other stakeholders to stimulate growth, liveability and innovation in the cities of Europe and to identify and successfully tackle social challenges (EC, 2019d).
- The **reference framework for sustainable cities** is an online toolkit for local European authorities that are involved in or are willing to start a process of integrated and sustainable urban development (Urbact, 2018).
- The **European Green Capital Award** rewards cities that are making an effort to improve the urban environment and move towards healthier and sustainable living areas (EC, 2019e).
- The **European Green Leaf** competition is open to cities with a population of between 20 000 and 100 000. It recognises success in achieving green growth and is awarded to cities that bring green living concepts to life (EC, 2019f).
- The **EnRoute** project explored how urban green infrastructure contributed to sustainability and mitigated environmental risks in 18 cities from across Europe (JRC, 2019).

In addition, the aim of United Nations Sustainable Development Goal 11.7 is to provide universal access to safe, inclusive and accessible green and public spaces, in particular for women and children, older persons and persons with disabilities, by 2030.

across Europe and on a finer scale within cities. As a result, the scope is narrow and does not capture the full range of ecosystem services provided by nature. Box 3.3 summarises some of the broader interlinkages between biodiversity and health, highlighting how diverse ecosystems benefit health and how biodiversity loss impacts on health. As a recent example, the transfer of the SARS-CoV-2 virus from wild mammals to humans that caused the COVID-19 pandemic is thought to have resulted from novel human-animal interactions in the food system.

Box 3.3 Interlinkages between biodiversity and health

The benefits of biodiversity for health

- Biodiversity in the form of pollinators, soil biota and natural pest controllers plays a critical role in supporting food production. A broad diversity of species, varieties and breeds underpins good nutrition and varied diets.
- Terrestrial and freshwater ecosystems underpin the water cycle and the provision of clean water supplies, regulating nutrient cycling, soil erosion and water purification.
- Many medicines are derived from naturally occurring products, such as antibiotics. A large proportion of antibacterial drugs can be traced back to products of natural origin. Plant, microbial and marine species hold vast potential for new medicinal products.
- The human body depends on microbiota to support functions such as the function of the gastrointestinal tract, the regulation of the immune system and the prevention of infections. Reduced contact with healthy ecosystems can reduce diversity in this human microbiota and lead to immune dysfunction and diseases, such as allergies and bowel diseases.
- Spending time in natural environments is also associated with improved mental health and increased levels of physical activity with consequent health benefits. The benefits of access to biodiverse green spaces are particularly high for urban residents of low socio-economic status. Interaction with nature can contribute to treatment for depression, anxiety and behaviour problems, including for children.
- Biodiversity contributes to ecosystem resilience and is essential for enabling the adaptation of our agricultural production systems to climate change. For example, new species may be drawn into agricultural production as the climate shifts. Vegetation reduces erosion and plays a role in flood mitigation, reducing the impact of natural disasters on health and well-being.
- Living organisms act as bio-indicators of human health stressors. For example, lichen act as indicators of air pollution, while crustaceans are an indicator species for water quality.

Direct effects of biodiversity loss on health

- Biodiversity loss can destabilise pathogen dynamics, in particular pest control, leading to increases in the population size and ranges of disease vectors, as well as spillovers across species, increasing the risk of infectious disease. Invasive species can carry disease, promote infections and expose humans to bites or stings.
- Eutrophication caused by excessive nutrient loading as a result of agriculture has a significant impact on surface water quality and can limit the availability of water supplies for drinking water.
- Biodiversity loss can lead to natural pest control species being removed from agricultural systems and can necessitate the use of chemical pesticides. This increases the potential for human health impacts to occur from exposure to hazardous chemicals as well as further impacts on non-target species.
- Land clearance can lead to erosion and the destabilisation of slopes, which can result in landslides or avalanches in extreme weather conditions, affecting local water bodies and leading to injury and death.

Sources: Based on WHO and SCBD (2015).

3.1 The health benefits of green and blue spaces

Key messages:

- Exposure to green space benefits health by reducing mortality and morbidity from chronic diseases, improving mental health and pregnancy outcomes, and reducing obesity.
- Socially deprived communities stand to benefit the most from the health benefits of natural environments, through reductions in stress, mortality and morbidity.
- Access to green space promotes community cohesion, reducing social isolation for minority groups and the elderly.
- Exposure to green spaces in school and around the home promotes healthy physical, emotional and cognitive development in children, securing health benefits for their future life.
- The pathways through which natural environments deliver benefits for health are physical exercise, relaxation and restoration, social cohesion and support of the immune system.

Spending time in high-quality natural environments improves our health and well-being. In terms of specific health outcomes, exposure to natural environments is associated with improved mental health and cognitive function, reduced cardiovascular morbidity, reduced prevalence of type 2 diabetes, reduced adverse pregnancy outcomes and reduced all-cause and cardiovascular disease mortality (WHO, 2016d). The pathways through which natural environments deliver benefits for health are physical exercise, relaxation and restoration, social cohesion and support of the immune system (see Figure 3.2). The relationship between levels of green space in a local neighbourhood and people's health and well-being is especially significant for low-income and deprived urban and suburban populations (Ward Thompson et al., 2016).

Nonetheless, those involved in the planning of green and blue spaces and green infrastructure should also be aware of the potential of these spaces to introduce health hazards. These can include allergens, such as pollen, disease vectors, such as ticks and mosquitoes, and physical injuries. However, these can be effectively managed through the appropriate design, maintenance and operation of green spaces (Lõhmus and Balbus, 2015).

3.1.1 *Benefits of nature for health and well-being*

High-quality natural environments, in particular green spaces, directly support health and well-being. Overall, the evidence base for the specific benefits of blue space is more limited. The evidence base is reviewed below with regard to the key benefits identified.

Reduced mortality and morbidity

A number of reviews have found positive associations between local access to nature and reduced mortality (Mitchell and Popham, 2008; Maas et al., 2009a), in particular for cardiovascular disease and respiratory disease (Richardson and Mitchell, 2010; Gascon et al., 2016). While less cardiovascular illness and lower blood pressure are likely to result from exercising in green areas, mere contact with nature has also been found to have a positive impact on heart rate and blood pressure (Pretty et al., 2011).

With respect to type 2 diabetes, a study from England found a lower prevalence among people living near a large area of green space (Bodicoat et al., 2014). Other studies found associations between neighbourhood greenness and reduced chances of having type 2 diabetes mellitus (Maas et al., 2009a; Astell-Burt et al., 2014).

Improved mental health

There is strong evidence of the mental health benefits of green space, related to avoiding chronic stress and attentional fatigue (WHO, 2016d). Spending time in nature reduces anxiety, depression and loneliness, while a lack of green space is associated with increased symptoms (Maas et al., 2009a). Simply viewing nature enhances emotional well-being (Morris, 2003).

A recent meta-analysis found a range of positive physiological responses associated with viewing or being in a natural environment, including significant reductions in diastolic blood pressure, salivary cortisol and heart rate (Twohig-Bennett and Jones, 2018). The stress-reducing effects of gardening have been evidenced through lower cortisol levels (Van den Berg and Custer, 2011).

Figure 3.2 Health and well-being benefits of green and blue spaces

A study in four European cities in Lithuania, the Netherlands and Spain found that time spent in green space delivered improved mental health and vitality (van den Berg et al., 2016). UK studies have linked access to high-quality natural environments to reduced psychological distress (Pope, 2018; White et al., 2013) and found that people moving to greener areas showed an improvement in their mental health (Alcock et al., 2014). Similarly, evidence from four large Dutch cities linked the quantity of green space close to homes with good self-reported health (van Dillen et al., 2012). A Swedish study found that spending time in forested areas supports the rehabilitation of individuals with stress-related mental disorders (Pálsdóttir et al., 2017).

While the benefits of blue space have received less attention, a recent review found a positive association between exposure to blue spaces and mental health, well-being and levels of physical activity (Gascon et al., 2017). Exposure to blue spaces has been found to lower psychological stress (Nutsford et al., 2016). A German study found that the well-being of city dwellers is particularly associated with blue space, through enhanced contemplation, emotional bonding, participation and physical activity (Völker and Kistemann, 2011). A study of university students in Bulgaria found that both blue and green spaces in the urban environment allow restoration, leading to better mental health (Dzhambov, 2018). Further research is needed to better understand the associations between blue spaces, health and well-being.

Improved maternal and foetal outcomes

Exposure to green space during pregnancy has been found to positively affect birth outcomes by increasing levels of physical activity, reducing stress, enhancing social contact among mothers and reducing maternal exposure to noise, air pollution and high temperatures (Dadvand et al., 2012). There is consistent evidence from several countries that exposure to greenness and the presence of green spaces close to homes during pregnancy is positively associated with birth weight (Dadvand et al., 2014a; Dzhambov et al., 2014; Markevych et al., 2014; James et al., 2015). A low birth weight is a major predictor of neonatal and infant mortality, as well as long-term adverse health effects. In a Lithuanian study, increased distance to a city park was linked to a higher risk of pre-term birth and a lower gestational age at birth (Grazuleviciene et al., 2015). Finally, there is some evidence for fewer depressive symptoms in pregnant women living near green spaces (McEachan, 2016).

Reduced obesity

A review of the relationship between green spaces and obesity that included studies from across Europe found that the majority of studies found associations between exposure to green space and reduced obesity (Lachowycz and Jones, 2011). However, not all studies have identified such a clear relationship. Dempsey et al. (2018) found that, in Ireland, older adults in areas with both the lowest and highest shares of green space have a higher probability of being obese than those in areas with intermediate shares of green space, suggesting that other characteristics of urban areas may be mediating this relationship (for example elements of accessibility or how vulnerable/safe people feel using these spaces). The factors that determine access to and use of green space are examined in more detail in Section 3.2.

3.1.2 Pathways for delivering benefits

The principal pathways through which nature contributes to health and well-being are physical activity, relaxation and restoration, and social cohesion. There is also emerging evidence of improved immune functioning linked to exposure to nature.

Relaxation and restoration

The restorative effect of contact with nature is explained by the theory that humans have an innate need for the natural environment in which we evolved. Spending time in natural environments helps people to recover from psycho-physiological stress and restore attention and energy in the case of mental fatigue (WHO, 2016d).

Regarding stress reduction, contact with nature has a positive effect on those with high levels of stress, as it relaxes them and allows them to shift towards a more positive emotional state (Ulrich et al., 1991). Natural areas also tend to be free from nuisance noise, which has also been shown to reduce stress levels and improve quality of life (EC, 2015a). Exposure to natural stimuli triggers a parasympathetic nervous system response that leads to feelings of enhanced well-being and relaxation. In terms of reducing mental fatigue, exposure to interesting and varied natural stimuli helps to improve performance in cognitive tasks. In contrast to the direct attention required by tasks, observing nature stimulates indirect fascination and so restores mental energy (Ohly et al., 2016). The level of species diversity within a green space has also been shown to influence the potential health benefits (Dallimer et al., 2012).

Physical activity

Parks, communal gardens and urban farms provide spaces for physical activity, such as jogging, gardening and walking, which have restorative impacts on health. There is some evidence to suggest that green space availability encourages physical activity (Pretty et al., 2011; Kabisch et al., 2015). Studies from several European countries have found walking, exercise and reduced sedentary time to be associated with access to green space for people of different age groups (WHO, 2016d). In a context in which physical inactivity is a leading risk factor for mortality, this offers a potential public health solution. Regular physical activity reduces the risk of ischaemic heart disease, diabetes, breast and colon cancers, stroke, hypertension and obesity (WHO, 2010).

Regarding mental health, exercising in green space has been found to deliver reductions in self-reported anger, fatigue, anxiety and sadness, with increased feelings of energy (Bowler, 2010a). People exercising in green spaces were found to have improved moods and self-esteem, with the presence of water generating greater effects (Barton and Pretty, 2010).

There are also various physical and psychological benefits derived from undertaking physical activity in natural aquatic environments (White et al., 2010; Ashbullby et al., 2013; White et al., 2016). As discussed in Section 4.5, the majority of bathing waters across Europe are in an excellent condition, providing European citizens with opportunities for recreation.

In terms of how access to green space links with physical activity, a Danish study found that people living within 300 m of green space were more likely to use green space to exercise than people living 1 km away. Those living further from green spaces have been found to be more likely to be obese (Toftager et al., 2011). French studies have found that high-quality green space is associated with recreational walking (Chaix et al., 2014) and with jogging among adults in Paris (Karusisi et al., 2012). In the United Kingdom, people living in coastal environments were found to be more likely to achieve the recommended rate of physical activity (White et al., 2013). Conversely, a Finnish study found that residential proximity to green space was associated with increased car use to reach workplaces, as, in Finland, homes surrounded by green space are often situated far from workplaces (Mäki-Opas et al., 2016).

Some evidence suggests that physical activity in nature leads to better health outcomes than exercising in artificial environments (Thompson Coon et al., 2011). Middle-aged adults reported feelings of restoration, positive emotions and vitality when walking home after work through an urban park or woodland, versus walking through the city of Helsinki in Finland (Tyrväinen et al., 2014). A project to promote walking in Ireland is described in Box 3.4.

Social cohesion

Positive social relationships foster health and well-being, while social isolation is a known predictor of morbidity and mortality (Yang et al., 2016). Green spaces in urban areas act as hubs for community interactions, foster social cohesion and reduce social tension, in particular for groups that are vulnerable to social exclusion (Burrage, 2011; Kaźmierczak, 2013; ten Brink et al., 2016). Community gardens and allotments can provide an arena for building social capital, whereby groups can meet to collaborate on joint projects, fostering social networking and raising environmental awareness (Veen et al., 2016).

A systematic review of available evidence found that interacting with nature facilitates social interaction, promotes social empowerment, reduces crime rates and violence, fosters interracial interaction and supports the provision of social support (Keniger et al., 2013). Studies from the Netherlands linked both the quantity and quality of neighbourhood greenery to social cohesion on a local scale (de Vries et al., 2013).

Improved immune functioning

The human microbiome plays a role in regulating the immune system. There is evidence suggesting that exposure to green space supports the healthy functioning of the immune system by fostering the development of a healthy microbiome (Rook, 2013; Kuo, 2015; Sandifer et al., 2015). An unhealthy microbiome is linked to allergies, asthma and other chronic inflammatory diseases, all of which are on the increase among urban populations. Exposure in early life to microbiota can reduce the likelihood of developing allergic sensitisation (Lynch et al., 2014; Ruokolainen et al., 2015).

3.1.3 The social benefits of nature

Socially deprived communities and minority groups

A limited body of evidence from the United Kingdom and the Netherlands suggests that people living in deprived neighbourhoods gain particular benefits in terms of health and well-being from access to green space. The benefits derive from an enhanced sense of belonging and reduced social isolation, as well as stress reduction and opportunities for physical activity. Access to green space in a neighbourhood may buffer some of the negative effects of stressors such as unemployment (Ward Thompson et al., 2016). Unfortunately, reaping the benefits for socially deprived communities conflicts with the reality of 'green gentrification', as described in Section 3.3, through which the availability of green spaces leads to higher property prices, excluding lower-income families.

Box 3.4 Encouraging walking for healthy hearts

In 1996, the Irish Heart Foundation established the 'Slí na Sláinte' project to promote regular walking among the population, as it has numerous health benefits, including cardiovascular and pulmonary benefits. Local authorities and local communities are encouraged to establish a health path/walking routes in their area. Walking can also have social benefits, as it provides a way to meet new people and maintain existing friendships. On some health paths, community walks are organised involving people from the local community or common workplaces (Irish Heart Foundation, 2019).

Focusing on social benefits, a study from the Netherlands found that the relationship between green space and social support was strongest for people with a low income or a low level of education, indicating that they may be more reliant on green space for social contact (Maas et al., 2009b). In the United Kingdom, ethnic groups mingle in urban parks, fostering a sense of community and attachment to place (Peters et al., 2010). Cross-cultural interactions in playgrounds enable the integration of minority groups and normalise interracial contact (Bennet et al., 2012). The use of urban nature by immigrants in Helsinki was found to help them identify with their new communities (Leikkilä et al., 2013). Urban forests in Ljubljana, Slovenia, were found to support community identity, suggesting that green space is an important element in establishing a sense of belonging (Hladnik and Pirnat, 2011).

In terms of stress relief, a UK study identified significant associations between access to high-quality green space and reduced psychological distress among a deprived urban population (Pope, 2018). A Scottish study found that higher levels of green space in residential neighbourhoods were linked to lower perceived stress levels and healthier cortisol levels among a deprived urban population of unemployed middle-aged men and women (Roe et al., 2013). Another study, also from Scotland, found that, as green space in a neighbourhood increased, levels of perceived stress decreased. In addition, the frequency of visits to green spaces and views of green space from the home were significant predictors of general health (Ward Thompson et al., 2016). This country-level evidence is supported by a European study of associations between mental well-being and economic strain. The study found that that good access to neighbourhood green space reduced the level of inequalities in mental well-being between well-off and socially deprived groups by 40 % (Mitchell et al., 2015).

Regarding mortality and morbidity, a UK study linked better access to green space to lower mortality in deprived areas (Lachowycz and Jones, 2014), while a Dutch study found that the relationship between lower morbidity and a green living environment was more significant for children and people of lower socio-economic status (Maas et al., 2009a). A project to increase and enhance green space in areas of deprivation in Scotland is described in Box 3.5, while activities to promote green space in urban areas in Germany are described in Box 3.6.

The links between positive birth outcomes and access to green space are discussed in Section 3.2.1. In terms of social differentiation, a UK study found that a positive association between the areas of greenness a mother can access during pregnancy and birth weight only applied to the white population and not to mothers of Pakistani origin (Dadvand et al., 2014a). This suggests that different perceptions and cultural norms affect the use and resulting benefits of green space.

Finally, regarding blue space, a UK study looked at visits to the coast involving walking and found that females, older adults and individuals from lower socio-economic groups were more likely to go on coastal walks, suggesting coastal amenities may support the reduction of activity inequalities (Elliot et al., 2018).

Children and adolescents

Green spaces offer particular benefits to children and adolescents. There is growing evidence of the beneficial effects of nature on the mental health and cognitive development of children (WHO, 2016d). Playing in nature stimulates the development of gross and fine motor skills, as well as cognitive, emotional, social and physical development (Strife and Downey, 2009). Exposure to green spaces in childhood facilitates

Box 3.5 Green infrastructure community engagement projects in Scotland

The Green Infrastructure Strategic Intervention, which is being delivered by Scottish Natural Heritage, aims to increase and enhance green space in areas of deprivation in Scotland. As part of this project, the Green Infrastructure Community Engagement Fund supports small-scale community participation projects, tailored to the specific communities with which they engage. Projects are designed from the bottom up, are locally relevant and are innovative for the area.

The projects involve groups of people working in the local area who both know and are invested in the communities that the projects will benefit. The main target groups are communities in deprived urban communities. The project aims to encourage people to value, use and enjoy their green spaces and, through this, feel happier, healthier and better connected to their communities. The objective is to reduce inequalities in health and opportunities, and increase how people value and understand the things that nature does for them. Green infrastructure can also help people develop skills and gain the confidence to seek and sustain jobs.

Source: Green Infrastructure Scotland (2019).

Box 3.6 German federal activities to promote green space in urban areas

In Germany, political actions at the federal level are increasingly focusing on the development of urban green spaces, with the aim of reaping the health and social benefits of these and contributing to environmental justice.

In 2017, the federal government launched a new urban funding programme entitled 'Future urban green spaces' (BMI, 2019), recognising the importance of green spaces in cities as part of urban planning funding programmes and aiming to improve the urban green infrastructure. The new programme also contributes to environmental justice through the fair distribution of high-quality urban green spaces.

In addition, in 2017, the federal government launched the *White paper — green spaces in the city* (BMUB, 2018). It recommends federal government actions to support municipalities and other stakeholders in strengthening urban green infrastructure. It puts an emphasis on developing urban green spaces in a socially just and healthy way.

In 2019, this white paper was followed by the 'Master plan for urban nature' (BMUB, 2019). With 26 measures in place, the federal government supports the municipalities to increase the diversity of species and biotopes in German cities. The aim is to create natural, green habitats that benefit plants and insects and provide space for recreation, physical activity and social interaction. Several measures explicitly emphasise environmental justice through the fair distribution of high-quality urban green infrastructure.

healthy development and offers benefits for the entire life course. Children who engage in outdoor physical activities at a young age are more likely to maintain such lifestyles into adulthood (Kabisch et al., 2017).

In terms of evidence from across Europe, a UK study found that urban green spaces are important locations for children to carry out physical activity (Lachowycz et al., 2012). UK research found that 11-year-old children living in greener urban neighbourhoods had a better spatial working memory (Flouri et al., 2019), and children raised in greener neighbourhoods showed greater cognitive ability at all ages (Reuben et al., 2019). Green schoolyards were found to improve well-being and reduce physiological stress in Austrian schools (Kelz et al., 2013). A study of 36 schools in Spain found that exposure to green spaces at home and at school is associated with significant improvements in working memory and a reduction in inattentiveness (Dadvand, 2015). For the Spanish study, this association was mediated by a reduction in exposure to air pollution. Other studies have also demonstrated the positive impact of green space exposure on attention deficit hyperactivity disorder (ADHD) and related symptoms (Amoly et al., 2014; Markevych et al., 2014). Children with attention deficit issues have been found to concentrate better after walking in the park, with parents observing improved symptoms after activities in green settings, compared with indoor activities (Faber Taylor and Kuo, 2009).

A Swiss study found that urban green spaces provide places for children and young people, in particular young immigrants, to develop their social networks, fostering cross-cultural friendships and promoting social inclusion (Seeland et al., 2009).

The elderly

Older adults are often the most sedentary segment of the community and also have an increased risk of chronic disease. There is limited research focusing on the benefits of green spaces specifically for elderly populations. A UK study found that higher levels of greenness around residential areas and living closer to natural environments contributed to better physical functioning at older ages, with proximity to both green and blue space associated with a slower decline in walking speed and grip strength (de Keijzer et al., 2018). In the Netherlands, senior adults living in proximity to green space reported better health (de Vries et al., 2003). Another Dutch study found that high-quality green spaces strengthened community networks among the elderly, with the safety and maintenance of the green spaces having been identified as important factors influencing use (Kemperman and Timmermans, 2014). Social interaction is especially important for older people, as social isolation is significantly associated with increased mortality.

3.2 Access to green space in urban areas

Key messages:

- Green space in urban areas fosters health and well-being. With green spaces offering significant benefits to disadvantaged groups, it is important to deliver equitable access to urban nature.
- Access to green space is determined primarily by proximity to residence, perceived safety, particularly for women and the elderly, and quality.
- There is significant variation in the accessibility of urban green space across Europe. In a quarter of European cities, the majority of the urban population have access to green space within walking distance, while in 10 % of cities more than a fifth of people have no green space within walking distance.
- There is evidence linking social deprivation to reduced access to urban green space from a few European countries. Higher house prices in greener residential areas is also a factor driving unequal access.

In a context in which 74 % of the EU population resides in cities (UN DESA, 2019), ensuring the provision of adequate green and blue spaces to support physical exercise and relaxation and provide places for people to meet and interact is an important public health issue. Effectively incorporating accessible, high-quality green space into the design of urban environments has the potential to promote physical activity and reduce the health burden of sedentary lifestyles (Sallis et al., 2016). Research on access to natural areas has focused on green space in urban areas, with a lack of evidence regarding access to blue space. Hence, this section focuses mostly on green space.

3.2.1 Factors determining access to urban green space

The extent to which urban residents make use of green and blue spaces is influenced by the accessibility, availability and proximity of green areas, the quality of the natural space and perceived safety. Since the health benefits linked to exposure to greenery may be highest among disadvantaged groups, it is important to deliver equitable access to urban nature across all societal groups.

There are also individual dimensions that will affect people's use of green space, such as their personal motivation to exercise. In addition, people may face barriers when accessing green space because of restraints on their personal mobility.

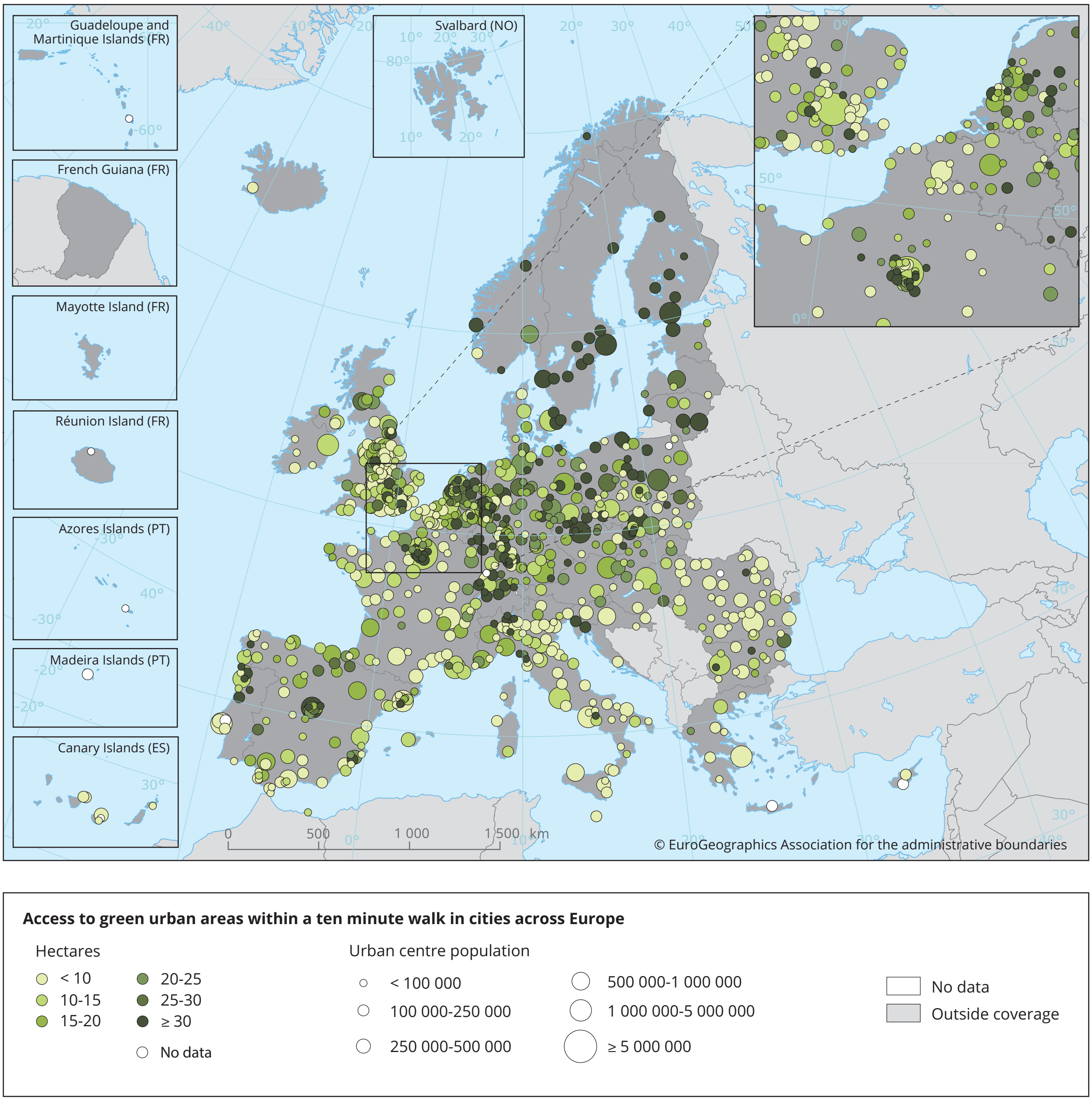
Availability and proximity

Studies suggest that distance to green space matters most for reaping the health benefits, with a walkable distance of around 500 m proposed as a guideline (Ekkel and de Vries, 2017). A European study assessed the area of green space that urban residents could reach within easy walking distance (10 minutes) across different European cities using the Copernicus Urban Atlas data (Poelman, 2018) — the results are presented in Map 3.1. The study found significant variation in the area of urban green spaces close to urban populations across Europe. There was no relationship between the proximity of urban populations to green space and city size. For capital cities with over 1 million inhabitants, the areas of easily accessible green space varied from 12 hectares in cities such as Athens, Bucharest, Budapest, Dublin, Lisbon, Paris and Rome to more than 50 hectares in Prague and Stockholm.

A positive finding is that, in about a quarter of the cities under review, including Glasgow, Madrid, Prague, Stockholm, Torino and Vienna, 98 % of the urban populations had green areas within walking distance. However in about 10 % of cities, including cities in Italy and Romania, over 20 % of people had no green space within walking distance. Importantly, the share of green space in the total city area was not indicative of proximity for urban populations. For example, while only 6.5 % of land in Thessaloniki is green, 98 % of the population are within walking distance of green areas (Poelman, 2018).

A 2016 study assessed the availability of green space in 299 European cities and confirmed the variation across Europe. Northern European cities were found to have a higher average availability of green space because of the presence of forests. In contrast, southern European cities showed below-average levels of green space availability, which can be explained by their low levels of tree cover and the historical structures of such cities (Kabisch et al., 2016).

Map 3.1 **Access to green urban areas within a 10-minute walk in cities across Europe**



Source: Poelman (2018).

Safety

People's interest in using a green or blue space can be affected by perceived risks to their personal safety. In areas of social deprivation, groups may engage in antisocial behaviour in green spaces, making others feel unsafe. In particular, women are more affected by safety concerns than men (Ward Thompson et al., 2016). A Dutch study found that the use of green spaces by the elderly was influenced by perceived safety (Kemperman and Timmermans, 2014). Safety issues should therefore be considered by urban planners looking to improve access to green and blue spaces.

Quality

Proximity to urban green space does not guarantee use; rather, use is influenced by typology, physical entry points, functions and quality (Poelman, 2018). Landscape attractiveness has been found to contribute to the frequency of visits to green areas (Roemmich et al., 2006). The presence of amenities, such as benches, parking and toilets, and the absence of litter, dog waste and graffiti increase the attractiveness of green spaces. A Dutch study found that the positive health effects of green spaces were related to quality elements, such as maintenance, safety and the absence of litter (van Dillen et al., 2012). Size is also a factor for physical activity (Ekkel and de Vries, 2017). Factors such as mixed land use and traffic levels can also influence the usability of green spaces and infrastructure. Health trails, cycling, walking and jogging routes, and opportunities for the infrastructure to be used to reach daily destinations, such as work, school and shops, can also increase usage.

3.2.2 Inequalities in access to urban green space and ecosystem services

Exploring how parks are spatially distributed relative to the needs of communities can inform urban planning in cities and towns so that it can provide more equal access. The distribution of green spaces in urban areas may be significantly biased towards certain locations and specific social groups (Schindler et al., 2018). European Quality of Life Surveys demonstrate a socio-economic gradient in access to green spaces (Eurofound, 2016). Deprived communities are more likely to live in densely populated urban areas, where access to green space can provide opportunities for relaxation and social interaction.

There is evidence of a link between social deprivation and reduced access to high-quality green space from a small number of European countries. An English study found that the provision of green space was worse in deprived areas than in affluent areas (Brown et al., 2010). In Greater Manchester, United Kingdom, it was shown that the richest 25 % of the population enjoyed access to 2.7 times as much green space as the most deprived 25 % (Drayson, 2014). A study in Porto, Portugal, found that deprived neighbourhoods had a higher average distance to green space, which was also of lower quality and had safety concerns, structural damage and fewer amenities (Hoffman et al., 2017). A recent Dutch study found links between aspects of social deprivation, higher levels of air pollution, lower levels of green space and a higher prevalence of depression (Generaal et al., 2019). While most districts in Berlin have sufficient access to green spaces in terms of area and proximity, access rates are lower for immigrant communities (Kabisch and Haase, 2014). A recent analysis of access to green and blue space and links to social deprivation in Ireland is presented in Box 3.7.

In terms of drivers of inequalities in access to urban green space, access to high-quality green space drives up house purchases and rental prices, thus excluding poorer households (Mitchell et al., 2015). Through 'green gentrification', households of lower socio-economic status are displaced from areas that have become valued for their green spaces (Cole et al., 2017).

Green spaces are under pressure in Europe, with ongoing urbanisation and densification eliminating or degrading urban green spaces. The economic value of land drives private landowners to favour property development over maintaining green areas. The conversion of private urban green space into built structures is often not offset by the provision of more publicly available green space (Haaland and van den Bosch, 2015). Maintaining green spaces also requires sustained investment, which presents barriers to city administrators at times of economic constraints. Across urban areas in 31 European cities, Fuller and Gaston (2009) documented a dramatic drop in green space per capita in cities with greater population densities and found that, as cities grow per capita, access to green space declines.

Box 3.7 Access to green and blue spaces in Ireland

A recent study from Ireland explored patterns in access to green and blue spaces, self-reported health and social deprivation on multiple scales.

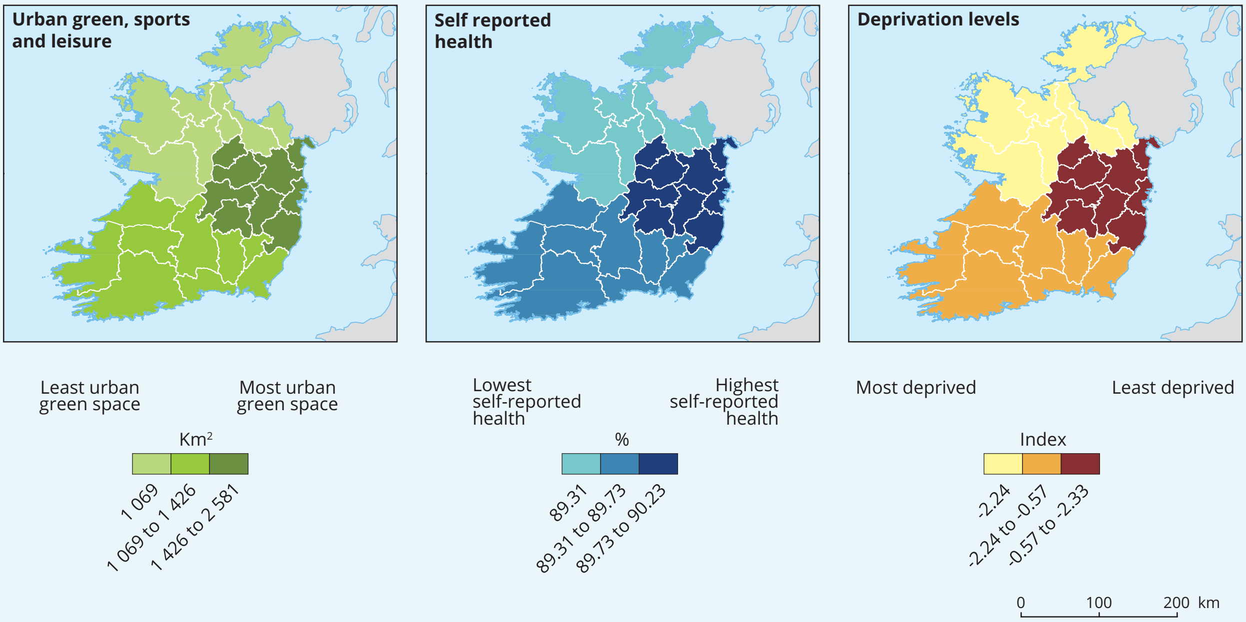
'Accessible' implies that a space is available for the general public to use free of charge and without time restrictions, although some sites may be closed to the public overnight and there may be parking fees. It also concerns physical access for public use, including an individual's access to the relevant equipment and clothing required for the respective uses, which may be limited by financial resources.

Usage refers to the repeated and multiple uses — including physical, recreational, conservation and cultural use — of blue and green spaces, facilities and activities by individuals, groups and communities.

Maps 3.2 and 3.3 below show the distribution of urban green and sports spaces, self-reported health and deprivation levels in three NUTS 2 ([a]) regions and counties (the local government administrative districts in Ireland).

Map 3.2 Patterns by NUTS 2 regions

Patterns by NUTS 2 regions



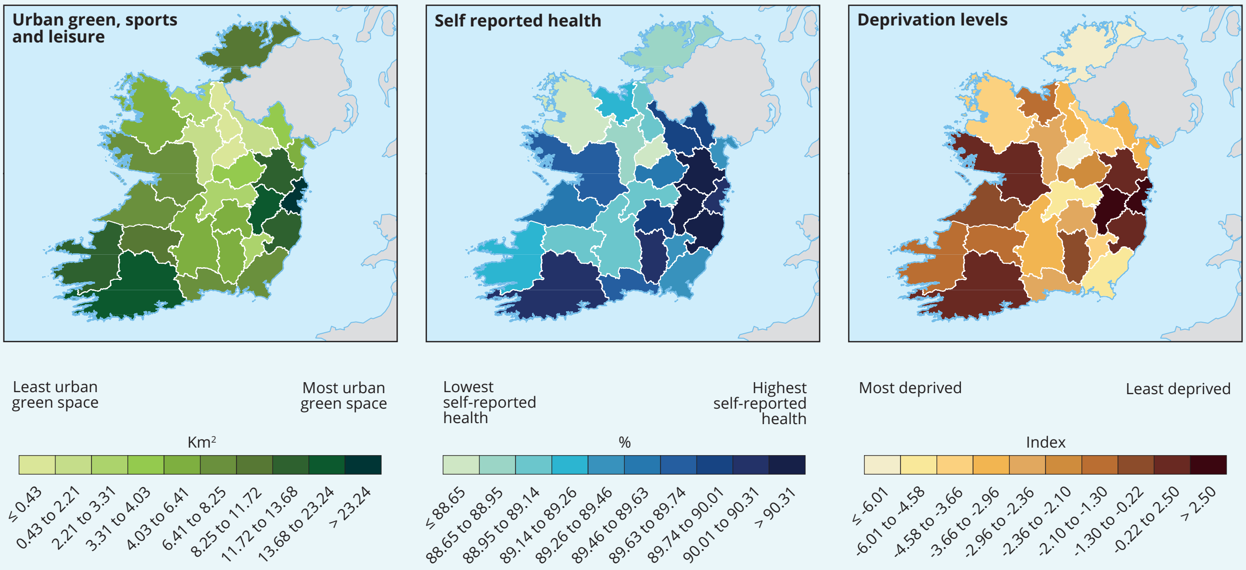
These findings suggest that there are regional and urban/rural divides in Ireland in relation to blue/green spaces, health outcomes and their socio-economic determinants.

The Eastern and Midland region (including Dublin city) has more blue/green spaces with facilities, higher rates of self-reported health and areas of higher affluence than the other two regions. The Southern region (including Cork city) is the middle-ranking region in all categories, while the Northern and Western region (including Galway city) is at the bottom end of the scale in all categories.

Box 3.7 Access to green and blue spaces in Ireland (cont.)

Map 3.3 Patterns by county

Patterns by county



When the correlations for all classes of green- and blue-related land use were calculated, access to sport and leisure space was found to be associated with deprivation.

The Healthy Ireland Outcomes Framework has been developed to monitor the achievement of the goals of Healthy Ireland related to health and well-being, associated lifestyle-related risks and the broader determinants of health (Healthy Ireland, 2019). The proposed domains include:

- social determinants of health, including socio-economic factors, such as poverty and income inequality, and environmental factors, such as air and water quality;
- health status, including lifestyle and behavioural risks, and the uptake of preventive measures, such as screening and immunisation;
- health outcomes, including morbidity and mortality, and well-being factors.

Note: ([a]) Nomenclature of Territorial Units for Statistics Level 2 (https://www.cso.ie/en/methods/revnuts23).

Source: Information and data provided by the National University of Ireland Galway, Ireland, with support from the Irish Environmental Protection Agency.

3.3 The environmental benefits of green and blue spaces

Key messages:

- Green and blue spaces can help to address the impacts of climate change, such as the urban heat island effect and floods. Urban green spaces can also stabilise urban temperatures and reduce energy requirements for the heating and cooling of buildings, thus reducing greenhouse gas emissions.
- Green spaces can increase noise attenuation and reduce the potential for noise nuisance, particularly in built-up areas.
- Green and blue spaces can support a reduction in water pollution by, for example, using green and blue spaces to collect/absorb rainwater, thus reducing the overall pressure of storm water on the sewer system and the potential for combined sewer overflows.
- Increased vegetation in urban spaces is also reported to be beneficial in terms of air quality; however, it is not a solution for urban air-quality problems.
- Urban vegetation can also contribute to carbon sequestration, although the effect may be minor in relation to the overall emissions of greenhouse gases in an urban area.

Green and blue spaces, or green infrastructure, can mitigate environmental risks and support the delivery of ecosystem services.

Specifically, green infrastructure can provide cool spaces during periods of heat, mitigate noise, support water run-off systems to reduce flooding and alleviate air pollution. These benefits are particularly relevant to urban areas, where there are dense populations exposed to air pollution, noise and, in some cases, extreme temperatures.

More broadly, green infrastructure can increase the resilience of urban ecosystems and enhance carbon storage over the longer term. Green space is needed for the healthy functioning of a city's ecological systems and to ensure the delivery of local ecosystem services for human health. While this is important, it is beyond the scope of this report and is therefore not considered further here.

The various pathways through which green infrastructure contributes to mitigating environmental risks are shown in Figure 3.3. Concrete examples of the implementation of nature-based solutions in urban areas are described in Boxes 3.8 to 3.12.

3.3.1 *Climate change and green space*

Green and blue spaces are likely to play a significant role in mitigating and adapting to the effects of climate change (Demuzere et al., 2014).

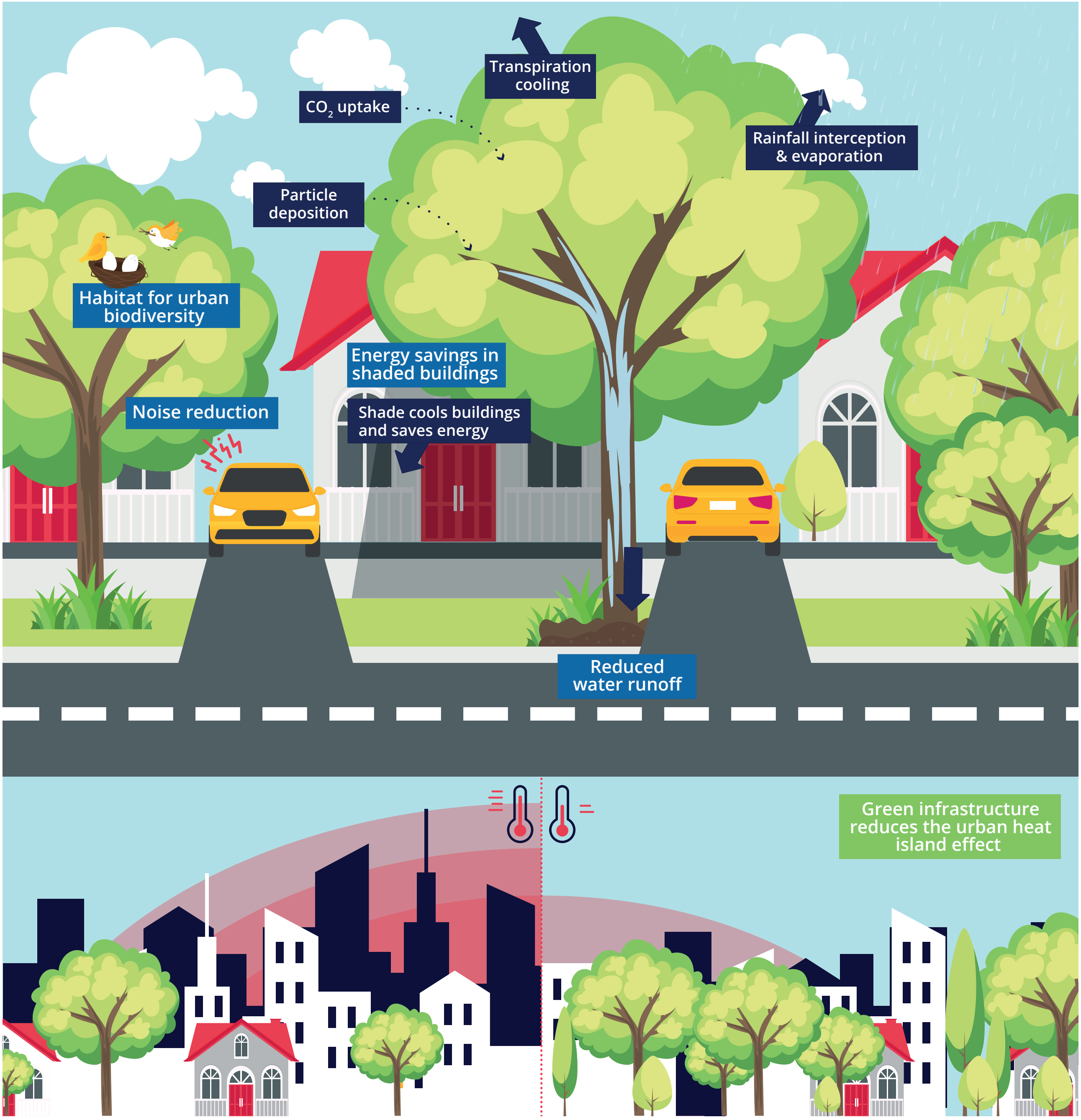
Urban heat

Urban temperatures are likely to increase over the coming century, along with associated health impacts (Breitner et al., 2014). In particular, the urban heat island effect can be counteracted by vegetation providing shade, as well as through the cooling process of evapotranspiration (Scott et al., 2016). The magnitude of the cooling in question is dependent on the type, size, health and density of the given vegetation. The canopy cover of trees is closely linked to resulting cool, with deciduous trees providing better cooling effects than coniferous trees (Meier and Scherer, 2012).

A systematic evidence review found that urban parks are, on average, 1 °C cooler than other urban environments, during both the day and the night (Bowler et al., 2010b). Furthermore, this cooling effect spreads out up to 1 km from the park boundary. Cooling can also result from street trees and green roofs in urban environments (Shisegar, 2014). The presence of water bodies in green space may induce greater cooling effects (Völker et al., 2013). For example, in Lisbon, Portugal, a cooling effect was demonstrated several kilometres from a body of water (Burkat et al., 2016).

These services may come at a cost, since local cooling through vegetation may only be possible through high levels of irrigation in warm, dry climates. The use of native species is generally considered preferable, as they are already adapted to local conditions and to maintaining a balance within the local ecosystem.

Figure 3.3 Examples of the benefits of green infrastructure



Source: Based on Livesley et al. (2016).

Reduced greenhouse gas emissions

Reducing the urban heat island effect also reduces building energy consumption, which has economic and environmental benefits (Francis et al., 2017). For example, in Chicago it was found that, by increasing tree cover in the city by 10 %, the total energy for heating and cooling was reduced by 5-10 % (Sorensen et al., 1997).

The effect that increased vegetation density has on greenhouse gas removal from the atmosphere is clear globally (IPCC, 2018). Although urban green spaces take in more carbon than they emit to the atmosphere, their contribution to greenhouse gas removal within cities is less clear cut. When a carbon footprint analysis was applied to an urban green space project in Leipzig, Germany, total net sequestration was predicted to range between 137 and 162 $MgCO_2$ per hectare

Box 3.8 Blue Green Dream

The Blue Green Dream project is dedicated to mapping and exploiting the benefits of nature-based solutions, to achieve urban sustainability and climate change resilience. The approach integrates both green and blue infrastructure, to provide these solutions.

The project has demonstration sites in France, Germany, the Netherlands and the United Kingdom. For example, in Paris, France, the hydrological behaviour of one hectare of green roof space is monitored to understand interactions between green infrastructure and water. These innovations demonstrate the benefits of blue and green spaces for climate change mitigation and adaptation.

The photo below shows the vegetated green roof called the Blue Green Wave, located at Cite Descartes, at the École des Ponts ParisTech campus.

Photo: © Climate-KIC / HM&Co École des Ponts Paris Tech.

The project produced a Blue Green Solutions Guide (Bozovic et al., 2017), including a framework for unlocking the multiple benefits of green infrastructure in cities to deliver resilient, sustainable and cost-effective solutions. The framework can be applied at the scale of the individual building, the neighbourhood and the city.

(Strohbach et al., 2012). Further research is required to understand these dynamics in different contexts.

Reduced flooding risk

With an expected increase in the frequency and severity of flooding events in Europe, there is a need for better protection. Urban trees and vegetation intercept and store water as part of urban catchment hydrology (Livesley et al., 2016). Similarly, urban blue spaces can store rainwater and prevent flood damage. Action taken by the city of Lisbon to adopt nature-based solutions for water management is described in Box 3.9.

Furthermore, green roofs have been shown to play an important role in storm water management in both northern (Richter and Dickhaut, 2016) and southern

Europe (Fioretti et al., 2010). A UK study determined that average rainfall retention on a green roof was 65.7 %, while for a bare roof it was 33.6 %. Annual rainfall retention for Manchester city centre could be increased by 2.3 %, as a result of a 10 % increase in green roofs (Speak et al., 2013).

3.3.2 Noise and green space

There are two main ways of reducing noise pollution: reduction at source through adaptation and noise abatement through anti-propagation measures. Vegetation can reduce sound levels through the absorption of sound energy and the redistribution of sound energy (ten Brink et al., 2016). In addition, noise levels are expected to be reduced in large green spaces, such as parks in cities. Vegetation in urban environments can also alter the individual perception of noise annoyance (Marry and Delabarre, 2011).

Vegetation, in particular tree belts, has also shown promise in achieving traffic noise reductions (Fang and Ling, 2003; Van Renterghem, 2014). There is the potential to generate significant noise reductions through the implementation of effective and intelligent urban planning. This is also linked to the concept of 'quiet areas', considered in Section 4.3.4.

Green roofs have been shown to reduce traffic noise (Yang et al., 2012). Green roofs may offer greater noise reduction potential in street canyons, as a ridge roof reduces traffic noise more than a flat roof (Van Renterghem, 2015).

3.3.3 Water quality and green space

The beneficial impacts that green spaces have on water quality can be significant. In urban areas, green infrastructure, such as bioswales, green roofs and rain gardens, can reduce water run-off into natural surface water bodies and reduce pollution load (Pataki et al., 2009; Gregoire and Clausen, 2011; Todorv et al., 2018). A review of green roof performance in managing run-off water indicated that there is a need for more research to identify the role that green roofs can play in urban drainage planning (Berndtsson, 2010).

Box 3.9 Green space in Lisbon

The Portuguese city of Lisbon won the European Green Capital Award for 2020. Lisbon was hailed as a role model for combining sustainability and economic growth, after undertaking major steps towards sustainable land use and urban mobility, promoting green growth and adopting nature-based solutions for water management and climate change adaptation.

In delivering sustainable land use, the municipalities established a network of nine green corridors, in order to counteract the effects of climate change, such as drought, extreme heat, and storm flooding. This green infrastructure also supports biodiversity and provides ecosystem services, including air pollution mitigation and space for recreation and urban farming. The city has planted 60 000 tress and seen a 16 % increase in new and renewed green space since 2008, expected to reach 20 % by 2022. There are 650 organic allotments using collected rainwater and composting organic waste, projected to increase to 1 000 by 2021. In Lisbon, 85 % of people already live within 300 m of green urban areas, with the municipality aiming to bring that proportion up to 93 %.

Under a masterplan for drainage in Lisbon, nine rainwater retention solutions have been constructed across the city to collect and store rainwater and reduce the effects of flash floods. Since 2013, the city has put in place efficiency and leakage control measures that reduced drinking water consumption by 50 %. Looking forward, recycled water will be used to water the city's green spaces.

In terms of action on climate change, Lisbon reduced CO_2 emissions by 42 % between 2002 and 2014, and reduced energy consumption by 28 % between 2012 and 2017. In 2016, Lisbon was the first capital in Europe to sign the New Covenant of Mayors for Climate Change and Energy.

Lisbon has a clear vision for sustainable urban mobility, with measures to restrict car use and prioritise cycling, public transport, and walking. In 2017, Lisbon launched a bike-sharing scheme, with electric bikes comprising two thirds of the fleet to encourage cycling in the hillier parts of the city. It has one of the world's largest networks of electric vehicle charging points, with 91 % of the municipal light duty car fleet made up by electric vehicles. In Lisbon, 93 % of people live within 300 m of public transport. Reducing the price of public transportation to EUR 1 per day drove a 30 % increase in the use of public transportation since April 2019.

Source: Private communication from Lisbon Municipality.

Box 3.10 The Hamburger Deckel

The Hamburger Deckel is an infrastructure improvement to one of Germany's busiest and longest motorways, the A7, which has six lanes and carries 152 000 vehicles daily (Petrov, 2014).

Increasing congestion prompted local residents to express concern over noise and air pollution, as well as the lack of access between districts on either side. The City of Hamburg announced the development of the Hamburger Deckel, which is to be completed by 2025. Construction began in 2012, replacing three sections of highway with tunnels and creating a variety of accessible green spaces, including open meadows, parks, community gardens and cycle paths.

The solution not only provides effective noise mitigation through intelligent urban planning measures but also reduces air pollution in the area and reconnects districts. It represents an example of how intelligent urban planning can be used to mitigate environmental risks.

Photo: © Behörde für Wirtschaft, Verkehr und Innovation Hamburg.

Denman et al. (2016) also found evidence of trees being able to remove nutrient pollutants and some heavy metals from storm water; however, the overall utility of this as a planned approach to attenuating storm water is very limited.

High rainwater loadings in combined sewer systems (i.e. systems that collect both rainwater and sewage) can also result in the release of untreated effluent when the receiving waste water treatment plant cannot accept the additional loading; such releases are known as combined sewer overflows. This is likely to become more prevalent in some areas, as climate change increases the likelihood of high rainfall events. The collection and/or absorption of rainwater by blue and green spaces can help to reduce the storm water loading in combined sewer systems and thus reduce the potential for combined sewer overflows (Pennino et al., 2016).

Furthermore, there may be benefits for water quality that can be accessed by using wetlands to treat

Box 3.11 Green networks in cities

There are several cities across Europe that use green corridors to promote clean airflows.

London's action plan 'All London Green Grid' (Greater London Authority, 2012) lays out plans to 'enhance London's strategic network of green and open natural and cultural spaces' and to increase the usage of these spaces.

Ljubljana's environmental protection programme presents its spatial plan for a network of green space or 'green system', connecting parks in the city with corridors and circular connections to the greener rural spaces outside the city, to generate airflows of clean air.

Barcelona City Council is developing a number of 'urban green corridors' through its green infrastructure and biodiversity plan 2020 (Barcelona City Council, 2012). These corridors will include strips with high concentrations of vegetation, to be used exclusively by pedestrians and cyclists.

domestic sewage or waste water. In urban areas, the use of constructed wetlands as a water-quality control system has increased (Thomas et al., 2016).

3.3.4 Air pollution and green space

Trees can help to improve ambient air quality. A study by the Nature Conservancy (2016) found that the average reduction in particulate matter (PM) near a tree was between 7 % and 24 %. In the United Kingdom, an estimated 1.4 billion kilograms of air pollutants were removed by natural vegetation in 2015, amounting to a saving of GBP 1 billion in health costs (Jones et al., 2016). In Strasbourg, France, it was estimated — using the i-Tree Eco model ([3]) — that, between 2012 and 2013, 88 tonnes of pollutants were removed from the city, representing 7 % of PM with a diameter of 10 µm or less (PM_{10}) emitted into the city's atmosphere (Selmi et al., 2016).

Green roofs have been shown to improve air quality within cities, with evidence suggesting that they may be able to remove PM_{10} from the air at a rate of between 0.42 and 9.1 g/m^2 per year (Francis et al., 2017). Pugh et al. (2012) found that the rate of pollutant deposition can be increased by planting vegetation in street canyons. This effect can reduce pollutant concentrations by up to 40 % for nitrogen dioxide (NO_2) and 60 % for PM. Green walls and roofs have also been shown to be more effective than trees in urban canyon settings (Pugh et al., 2012).

However, some research has warned of the dangers of overestimating the extent to which urban trees are able to appreciably affect atmospheric concentrations in polluted cities (Pataki et al., 2009). In reality, the extent of the beneficial effects will depend on the use of intelligent planning and the species of tree used in a particular location (Yang et al., 2015). Research by the UK Air Quality Expert Group concluded that 'overall, vegetation and trees in particular are regarded as beneficial for air quality, but they are not a solution to the air quality problems at a city scale' (Air Quality Expert Group, 2018).

In some situations, trees may actually exacerbate local pollution by reducing the air ventilation (Vos et al., 2013). As a result, planting hedges or green walls may be more desirable than planting trees in certain locations (Pugh et al., 2012). In addition, plants and trees emit volatile organic compounds, which can result in the formation of ozone and PM (Sartelet et al., 2012). These effects are known as ecosystem disservices, and they are likely to be species and site specific (Pataki et al., 2009). Plants can also generate pollen, which can have an impact on people who suffer from hay fever or asthma.

([3]) https://www.itreetools.org/eco

Box 3.12 High-rise forests — Milan's Bosco Verticale

Given the constraints that cities place on urban planners in terms of space, there has been a suite of increasingly innovative ways to increase the area of tree cover in cities.

Bosco Verticale (Vertical Forest) is the brainchild of architect Stefano Boeri. It is a pair of residential towers in Milan, Italy. The towers are home to 800 trees and 11 000 plants, which together transform about 19 000 kg of CO_2 into oxygen each year. Vertical vegetation offers a way for planners to increase the area of urban vegetation within cities (Architetti, 2014). One of the two Bosco Verticale towers in Milan is shown below.

Photo: © Kent Wang.

4 Environmental impacts on health and well-being

4.1 Introduction

A range of environmental stressors can degrade the condition of the environment and present risks to human health and well-being, as well as result in broader environmental impacts, for example biodiversity loss. A number of environmental risks are examined in detail in the following sections, including ambient air pollution, noise, climate change, poor-quality water, chemicals, indoor air quality and radiation. Environmental risks are not evenly distributed across society, both in terms of exposure to risks and the resulting impacts on health (see Box 4.1).

In addition, the cumulative effects of exposure to multiple stressors are examined. Understanding of the links between the environment and human health has evolved from perceiving them as isolated issues to recognising the interdependencies between complex systems, which means that these issues must be addressed at a more systemic and integrate level.

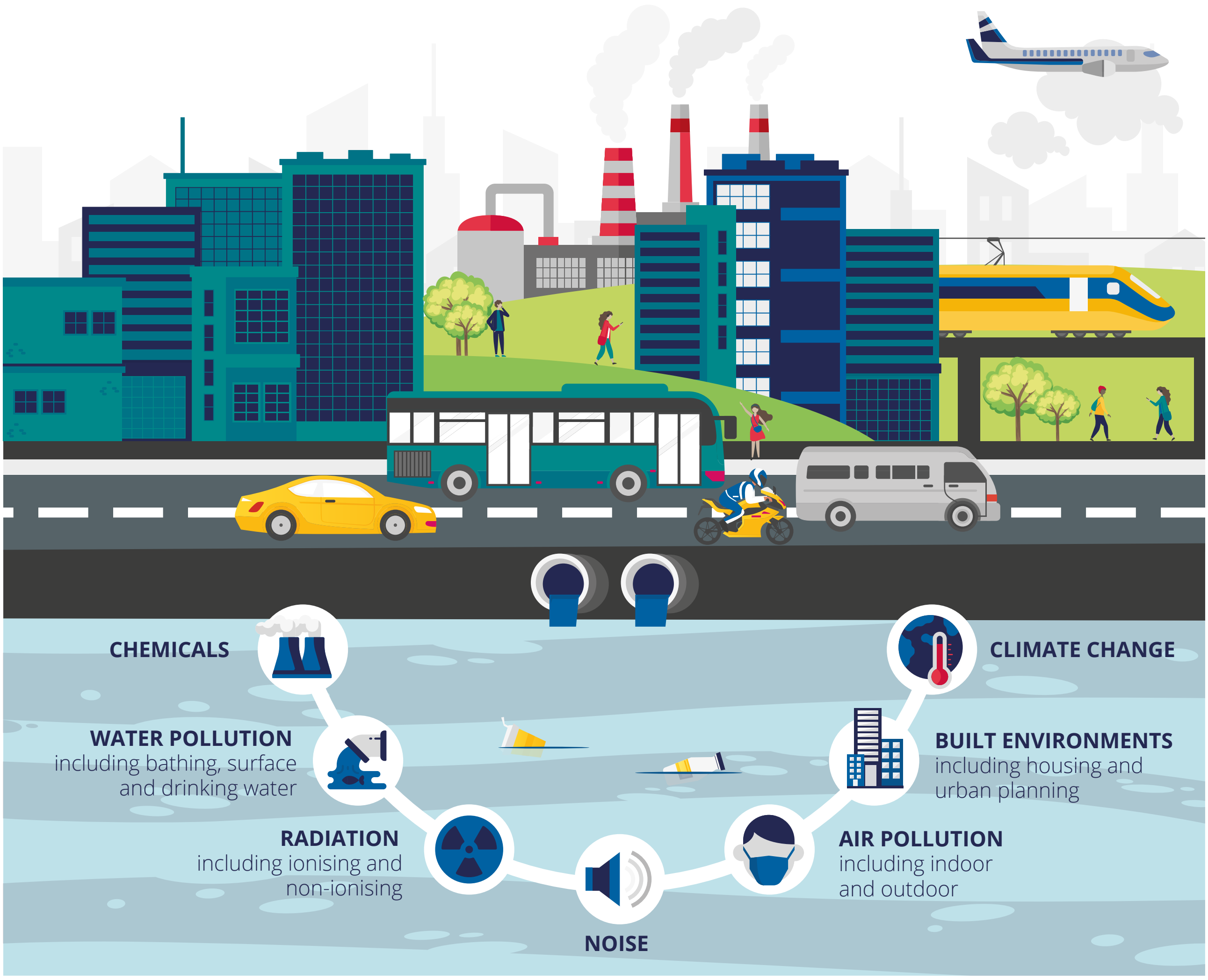
The evidence presented in the following sections not only clearly illustrates the negative effects that environmental pollution is currently having on our health and well-being but also highlights the opportunities to put in place measures to address key drivers of the environmental burden of disease and improve quality of life, which at the same time will help to address issues such as climate change and biodiversity loss.

Box 4.1 The vulnerability of children to environmental stressors

Children are more vulnerable than adults to environmental risks. First, they breathe more air, consume more food and drink more water than adults in proportion to their weight. Second, the central nervous, immune, reproductive, endocrine and digestive systems of a child are still developing. During certain critical windows of vulnerability, exposure to environmental contaminants can lead to irreversible damage. Third, children behave differently from adults and have different patterns of exposure to environmental hazards. Young children crawl on the ground and can therefore be exposed to dust and chemicals that accumulate on floors and soils. Finally, children have little control over their environments. Unlike adults, they may be both unaware of risks and unable to make choices to protect their health. Because of these unique vulnerabilities, children need special protection from environmental hazards.

Source: WHO (2017c).

Figure 4.1 Overview of environmental stressors addressed in this report



Source: EEA.

4.2 Ambient air quality and health

Key messages:

- Air pollution is the single largest environmental health risk in Europe, with around 400 000 premature deaths attributed to air pollution in Europe in 2018.
- Mortality attributed to air pollution results from ischaemic heart disease, stroke, chronic obstructive pulmonary disease, cancers and respiratory infection. Air pollution is also associated with neurological disorders, asthma, diabetes and obesity.
- Children, pregnant women, the elderly and those with pre-existing health conditions are most sensitive to the health impacts of air pollution.
- Concentrations of particulate matter (PM) — a key air pollutant linked to serious health impacts — exceeded EU limit values and stricter World Health Organization air quality guidelines in large parts of Europe in 2018.
- People of lower socio-economic status tend to live, work and go to school in places with worse air quality.
- Eastern Europe and south-eastern Europe are both poorer and more polluted than the rest of Europe, with particulate matter emitted from the burning of solid fuel for residential heating and cooking.

Air pollution is the single largest environmental health risk in Europe and has significant impacts on the health of the European population, particularly in urban areas. Europe's most serious pollutants, in terms of harm to human health, are particulate matter (PM), nitrogen dioxide (NO_2) and ground-level ozone (EEA, forthcoming). This section documents the impacts of outdoor air pollution on health, including the sensitivity of vulnerable groups to air pollution. The uneven distribution of exposure to air pollution across Europe is also considered. An overview of relevant policies is provided in Box 4.2.

4.2.1 Health impacts of air pollution

Air pollution causes a wide range of diseases — as outlined in Figure 4.3 — in particular respiratory and cardiovascular diseases. Short- and long-term exposure of children and adults to air pollution is linked to reduced lung function, respiratory infections and aggravated asthma. Air pollution is classified as carcinogenic (IARC, 2013), while emerging evidence links exposure to air pollution to new-onset type 2 diabetes, obesity, systemic inflammation, ageing, Alzheimer's disease and dementia (WHO Europe, 2016a). The EU-funded European Study of Cohorts for Air Pollution Effects ([4]) identified a significant link between PM and the incidence of lung cancer (Raaschou-Nielsen et al., 2013). A recent global review found that chronic exposure can affect every organ in the body, complicating and exacerbating existing health conditions (Schraufnagel et al., 2019). Emerging evidence suggests that chronic exposure to air pollution may play a role in driving susceptibility to COVID-19, with further research required.

Air pollution also has considerable economic impacts, cutting lives short, increasing medical costs and

([4]) Escape (http://www.escapeproject.eu/index.php).

Box 4.2 An overview of ambient air quality policy

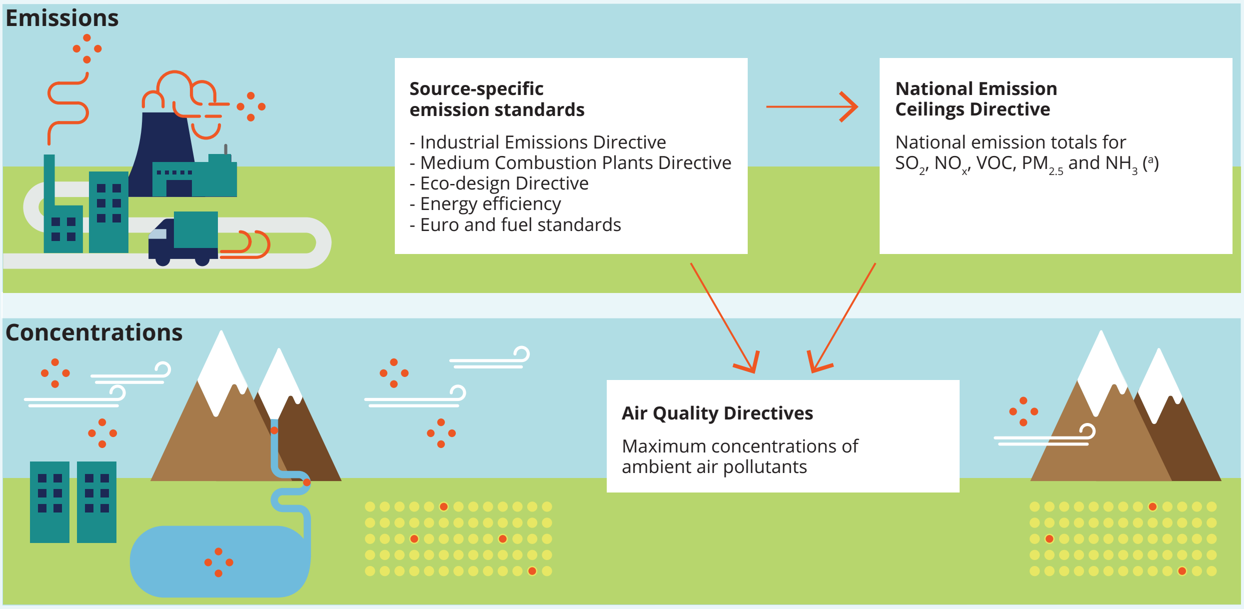
Improvements in ambient air quality in Europe are driven by two directives: the Ambient Air Quality Directive (Directive 2008/50/EC) (EU, 2008a) and Directive 2004/107/EC (EU, 2004). These specify air quality standards, known as limit values or target values, for a range of pollutants. They also specify how, where and when these pollutants should be monitored. Competent authorities are required to implement measures to improve air quality if limit values are exceeded and to maintain these standards when air quality is good.

The World Health Organization (WHO) has published air quality guidelines for specific pollutants, based on health impacts (WHO, 2006). For several pollutants, the WHO guidelines are more stringent than current EU standards, and the standards are currently being reviewed by the WHO. Some European countries have chosen to apply these more stringent WHO standards on a national basis. Under the European Green Deal, the Commission is expected to propose to revise air quality standards to align them more closely with the World Health Organization recommendations (EC, 2019a).

The EU Seventh Environment Action Programme includes the action to safeguard the EU's citizens from environment-related pressures and risks to health and well-being by ensuring that, by 2020, 'outdoor air quality in the Union has significantly improved, moving closer to WHO recommended levels' (EU, 2013a).

Ambient air quality policies are also intrinsically linked to legislation on emissions of air pollutants, which regulates the sources. These relationships are summarised in Figure 4.2. The EEA annual report on air quality in Europe provides further background information on international and EU policies (EEA, 2019c).

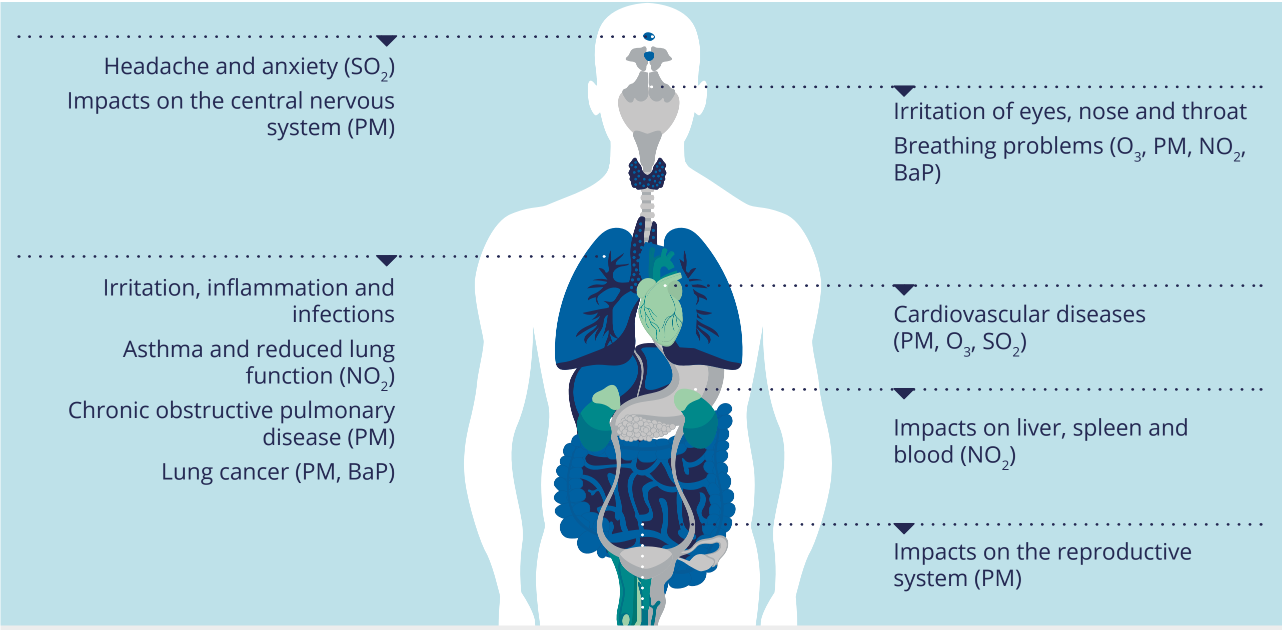
Figure 4.2 EU clean air policy — the policy framework



Note: Sulphur dioxide (SO_2), volatile organic compounds (VOC), particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$), nitrogen oxides (NO_x) and ammonia (NH_3).

Source: EEA.

Figure 4.3 Major sources of ambient air pollution and potential human health impacts



Particulate matter (PM) are particles that are suspended in the air. Primary PM emissions result from the combustion of solid and liquid fuels, such as for power generation, domestic heating and in vehicle engines. Road transport emissions also include non-exhaust emissions from brake, tyre and road wear and road dust resuspension. PM also forms in the air from secondary PM precursors, including ammonia, nitrogen oxides, sulphur dioxides and non-methane volatile organic compounds. Natural sources result from the transport of desert dust and wildfires.

Sulphur dioxide (SO_2) is emitted when sulphur containing fuels are burned for heating, power generation and transport. Volcanoes also emit SO_2 into the atmosphere.

Nitrogen dioxide (NO_2) is formed mainly by combustion processes such as those occurring in car engines and power plants.

Benzo(a)pyrene (BaP) originates from incomplete combustion of fuels. Main sources include wood and waste burning, coke and steel production and motor vehicles' engines.

Ground-level ozone (O_3) is formed by chemical reactions (triggered by sunlight) involving pollutants emitted into the air, including those by transport, natural gas extraction, landfills and household chemicals.

Source: Based on EEA (2013).

reducing productivity through working days lost across the economy.

Fine PM — particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$) — is one of the most relevant pollutants linked to health problems and premature mortality. It is estimated that, in 2018, there were about 379 000 premature deaths in the 28 Member States of the EU (EU-28) attributable to $PM_{2.5}$. Furthermore, 19 400 deaths were attributable to ozone exposure and 54 000 to NO_2 exposure ([5]) (EEA, forthcoming).

In terms of non-communicable diseases causing deaths attributable to air pollution, ischaemic heart disease is most significant, with over 112 000 deaths in the EU-28 in 2016, according to World Health Organization (WHO) estimates (WHO, 2018a). Other significant diseases attributed to air pollution and leading to deaths include lung cancer, stroke and chronic obstructive pulmonary disease, with the percentage of deaths from these non-communicable diseases that is attributable to air pollution in the WHO European Region presented in Table 4.1.

Nevertheless, premature deaths due to $PM_{2.5}$ have reduced significantly since 1990, when approximately 1 million premature deaths were linked to $PM_{2.5}$ (EEA, 2018b). The overall trend in premature deaths associated with $PM_{2.5}$ is shown in Figure 4.4 and can be explained through the successful reduction in emissions driven by policy requirements. Reducing

([5]) Note that premature deaths attributable to individual pollutants should not be added.

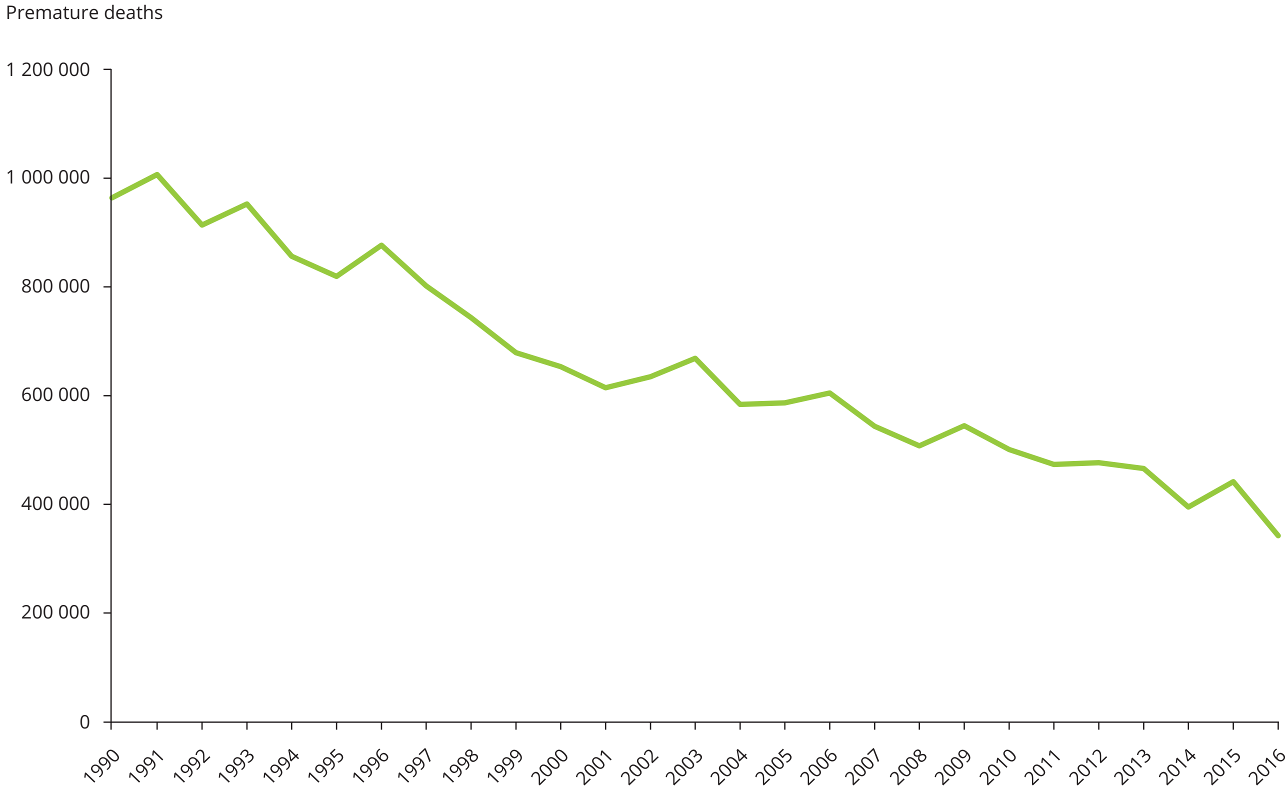
Table 4.1 Percentage of deaths from non-communicable disease attributable to ambient air pollution in the WHO European Region

Non-communicable diseases	Percentage of deaths attributable to ambient air pollution
Ischaemic heart disease	12 %
Lung cancer	17 %
Stroke	11 %
Chronic obstructive pulmonary disease	3 %

Notes: Data is for the WHO European Region.

Source: WHO (2017b).

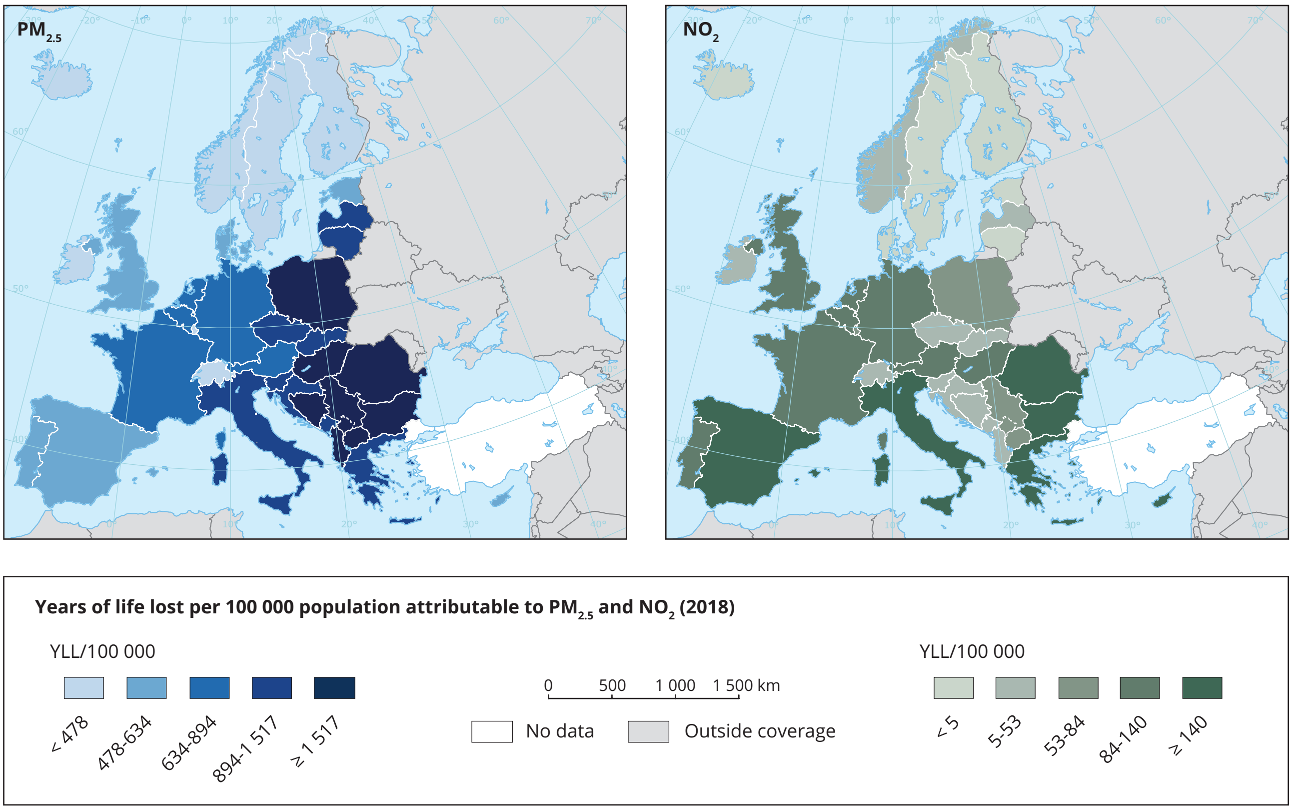
Figure 4.4 Premature deaths due to exposure to $PM_{2.5}$ in Europe over the period 1990-2016



Note: The figure shows an average across a number of different estimates of premature deaths.

Source: Based on EEA (2018b).

Map 4.1 **Years of life lost per 100 000 of the population attributable to $PM_{2.5}$ (left) and NO_2 (right) in 2018**



Note: The ranges of YLL/100 000 represent quintiles of the population.

Source: EEA (forthcoming).

$PM_{2.5}$ concentrations further will continue to bring about health benefits and reductions in premature deaths (EEA, 2019c).

Another way of measuring the impact of air pollution on health in terms of mortality is by estimating years of life lost (YLL) (see definition in Box 2.2). Map 4.1 indicates that the greatest impacts of $PM_{2.5}$ on YLL are seen in central and eastern European countries, with the lowest impacts seen in north and north-west Europe. For NO_2, the pattern is different, with YLL being highest in western Europe and lowest in northern Europe.

In addition to the above 'classical' air pollutants, there are certain pollutants that are not taken into account in regulatory monitoring that may also have an impact on human health. For example, an appraisal by the French Agency for Food, Environmental and Occupational Health and Safety (ANSES) highlighted the need to collect data on ultrafine particles, black carbon and 1,3-butadiene (ANSES, 2018). With these pollutants excluded from current health impact assessments, underestimations are likely. In particular, the impact of mixtures of pollutants is also not captured.

4.2.2 Sensitivity of vulnerable groups

Air pollution affects people in different ways. Individuals may be more sensitive to the health impacts of air pollution because of their age, pre-existing health conditions and particular behaviours. The most deprived people in society often have poorer health and less access to high-quality medical care, increasing their vulnerability.

Air pollution can compound existing health conditions. A study in Wales found that all-cause mortality and respiratory disease mortality were highest in the most deprived areas, as air pollution compounded the effect of deprivation on health (Brunt et al., 2017). 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., 2017). However, in some cases the evidence is not as clear; in another study, pre-existing risk factors for stroke did not increase susceptibility to the effects of air pollution on stroke risk (Maheswaran et al., 2016).

Age also affects sensitivity to air pollution. For example, in London, air pollution levels were associated with the number of older people admitted to hospitals for cardiovascular and respiratory diseases (Halonen et al., 2016). A study in Dublin also linked higher 30-day mortality (i.e. mortality within 30 days of admission) in elderly hospital patients to higher levels of nitrogen oxide (NO_x) pollution on their admission day (Cournane et al., 2017).

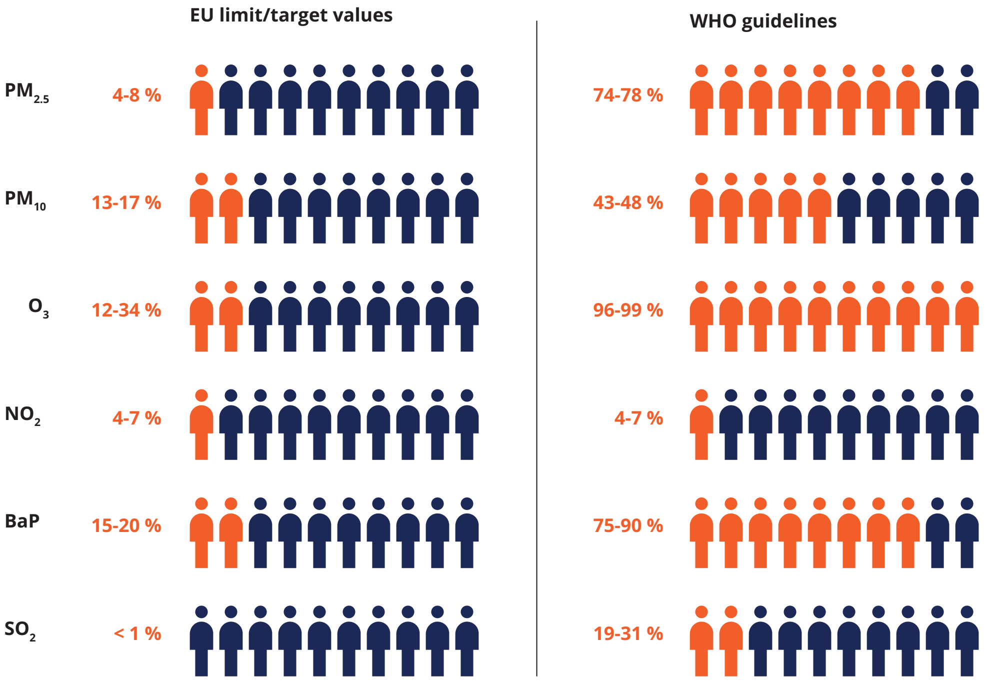
For children, air pollution has a negative effect on neural development and cognitive capacities, which in turn can affect performance at school and later in life, leading to lower productivity and a lower quality of life (Unicef, 2017). Exposure to traffic-related air pollution in infancy has been associated with reduced lung function that extends into adolescence (Schultz et al., 2016).

Pregnant women are considered to be at greater risk from air pollution, with maternal exposure to ambient air pollution associated with adverse impacts on fertility, pregnancy, newborns and children (WHO, 2018f). Recent research found that fine particles can cross the placenta, leading to foetal exposure (Bové et al., 2019).

4.2.3 Exposure to air pollution across Europe

Large parts of the EU population continue to be exposed to levels of air pollution known to damage health. Figure 4.5 presents the percentages of people in the EU urban population exposed to key air pollutants above EU limit or target values and above the WHO

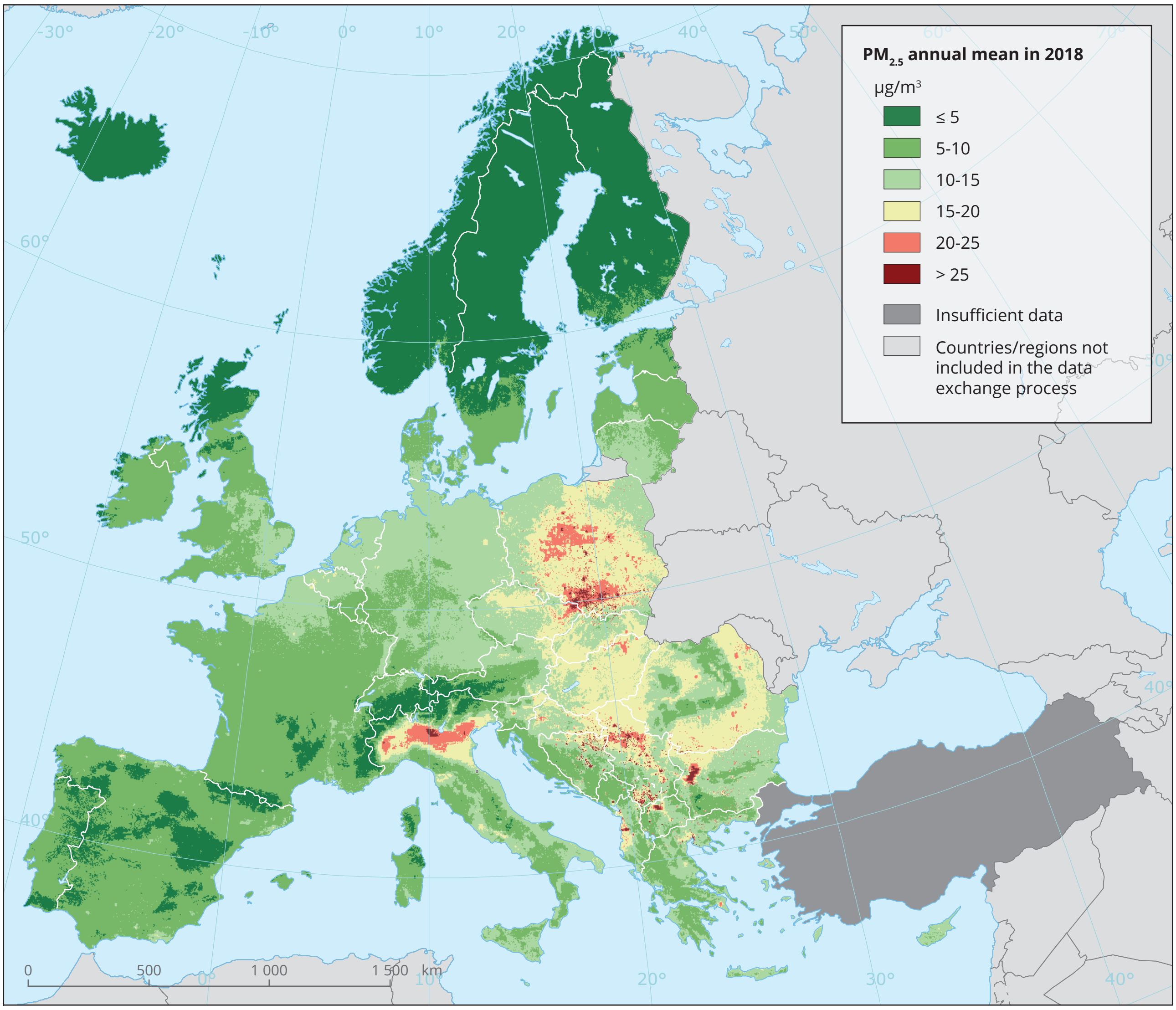
Figure 4.5 Percentages of the EU urban population exposed to air pollution concentrations above EU and WHO reference values during the period 2016-2018



Note: Particulate matter with a diameter of 2.5 μm or less ($PM_{2.5}$), particulate matter with a diameter of 10 μm or less (PM_{10}), ozone (O_3), nitrogen dioxide (NO_2), benzo[a]pyrene (BaP) and sulphur dioxide (SO_2).

Source: EEA.

Map 4.2 Concentration interpolated map of $PM_{2.5}$ (annual mean, µg/m³) for 2018

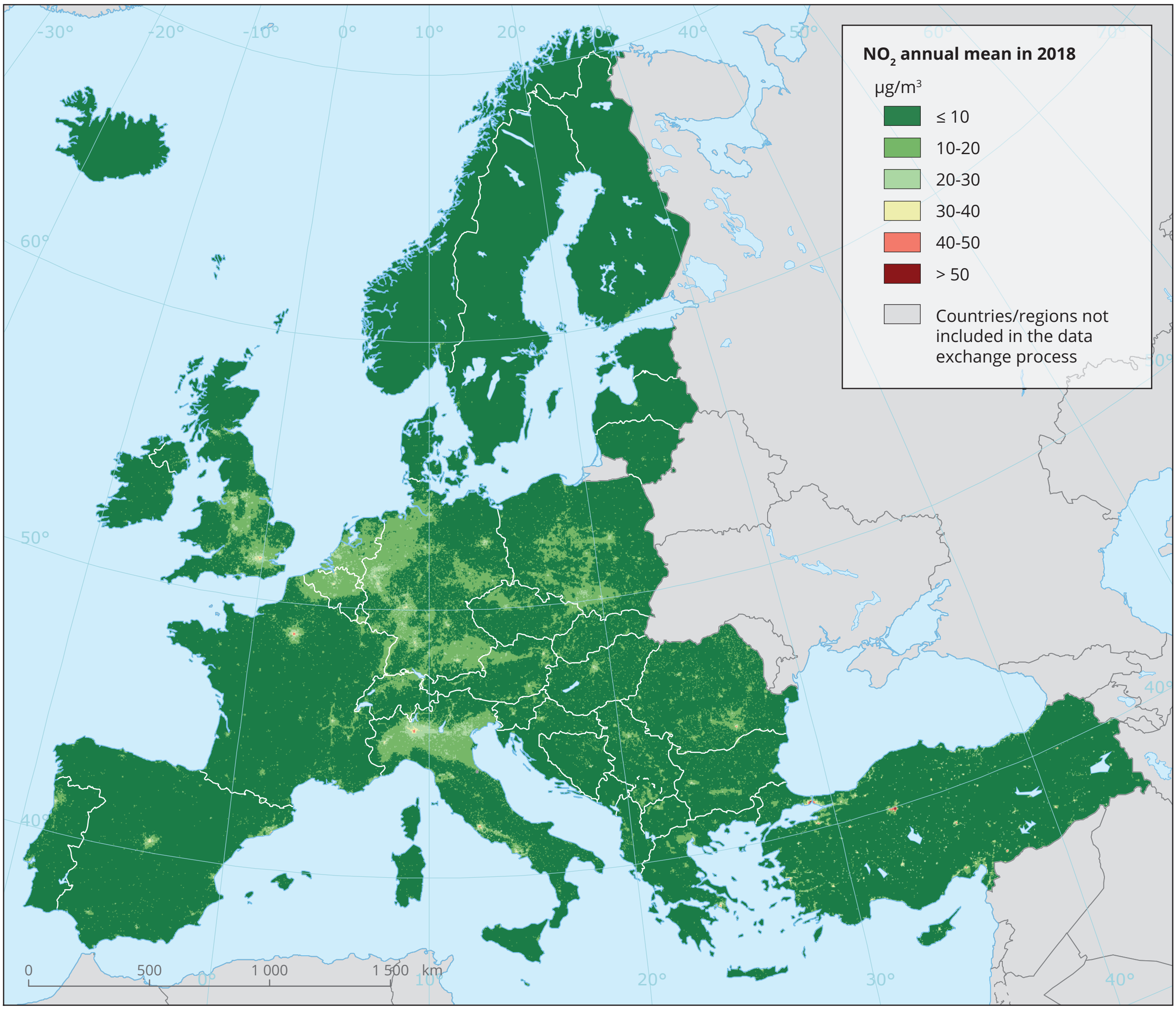


Source: EEA (forthcoming).

health-based guidance values during the period 2016-2018. Concentrations of PM exceeded EU limit values and WHO air quality guidelines in large parts of Europe in 2018. In addition, in 2018, 15 % of the EU-28 urban population was exposed to levels of PM with a diameter of 10 µm or less (PM_{10}) above the daily limit value, while 48 % was exposed to PM_{10} levels above the stricter WHO air quality guideline value. For $PM_{2.5}$, the respective figures were 4 % and 74 %, while 99 % of the EU urban population was exposed to ozone levels above the WHO guideline value (EEA, forthcoming).

Specific patterns are observed in terms of variation in exposure to air pollution across Europe. For PM (e.g. $PM_{2.5}$), levels in eastern Europe are higher because of the higher levels of emissions (see Map 4.2). NO_2 concentrations are highest in the more densely populated areas and are related to local sources, such as traffic, domestic and industrial emissions (see Map 4.3). Ozone is formed in the atmosphere as a result of reactions involving other pollutants, driven by sunlight. Warmer regions with more sunlight therefore tend to have higher ozone concentrations, resulting in a north-south divide. Exposure to benzo[a]pyrene (BaP), an indicator of polycyclic aromatic hydrocarbons (PAHs), is more significant in central and eastern Europe (EEA, forthcoming). The main sources of BaP in Europe

Map 4.3 Concentration interpolated map of NO_2 (annual mean, μg/m³) for 2018



Source: EEA (forthcoming).

are domestic heating (wood and coal burning), waste burning, coke production and steel production.

4.2.4 Social distribution in exposure to air pollutants

There is strong evidence linking lower socio-economic status to increased exposure to air pollution. In large parts of Europe, poorer people are more likely to live next to busy roads or industrial areas and so face higher levels of exposure to air pollution.

At the same time, exposure patterns vary across European cities. In some cities, wealthier people live in central, polluted areas, while in other European cities central areas are inhabited by poorer communities. A study in England and the Netherlands (Fecht et al., 2015) found populations with the lowest socio-economic status to be exposed to the highest concentrations of PM_{10} and NO_2. Other studies found people of lower socio-economic status to be exposed to higher levels of NO_2 in London, Lille and Marseille (Aether, 2017; Padilla et al., 2016), and PM_{10} and NO_2 in Dortmund (Shrestha et al., 2016). In contrast, in Bristol (United Kingdom) and Rotterdam (Netherlands), the most and least deprived neighbourhoods were exposed to similar concentrations of PM_{10} and NO_2, explained by the fact that affluent people live in polluted, city centres in these cities (Fecht et al., 2015).

On a regional scale, a Europe-wide study (Richardson et al., 2013) found that income-related inequalities in exposure to PM_{10} contributed to mortality inequalities specifically in eastern Europe but not in western Europe. The study also found people living in lower-income regions to be more susceptible to the health effects of PM_{10} than wealthier people living in polluted areas. Therefore, even when exposed to the same level of pollution, those of lower socio-economic status can be more negatively affected. This could relate to factors such as access to healthcare, underlying health conditions and poor housing conditions.

A recent EEA assessment explored the association between exposure to air pollution and dimensions of social vulnerability in regions across Europe ([6]) (EEA, 2018a). Areas characterised by lower socio-economic status were found to have higher levels of $PM_{2.5}$, PM_{10} and ozone pollution. For NO_2, the opposite was found, with wealthier areas experiencing higher levels of NO_2 pollution.

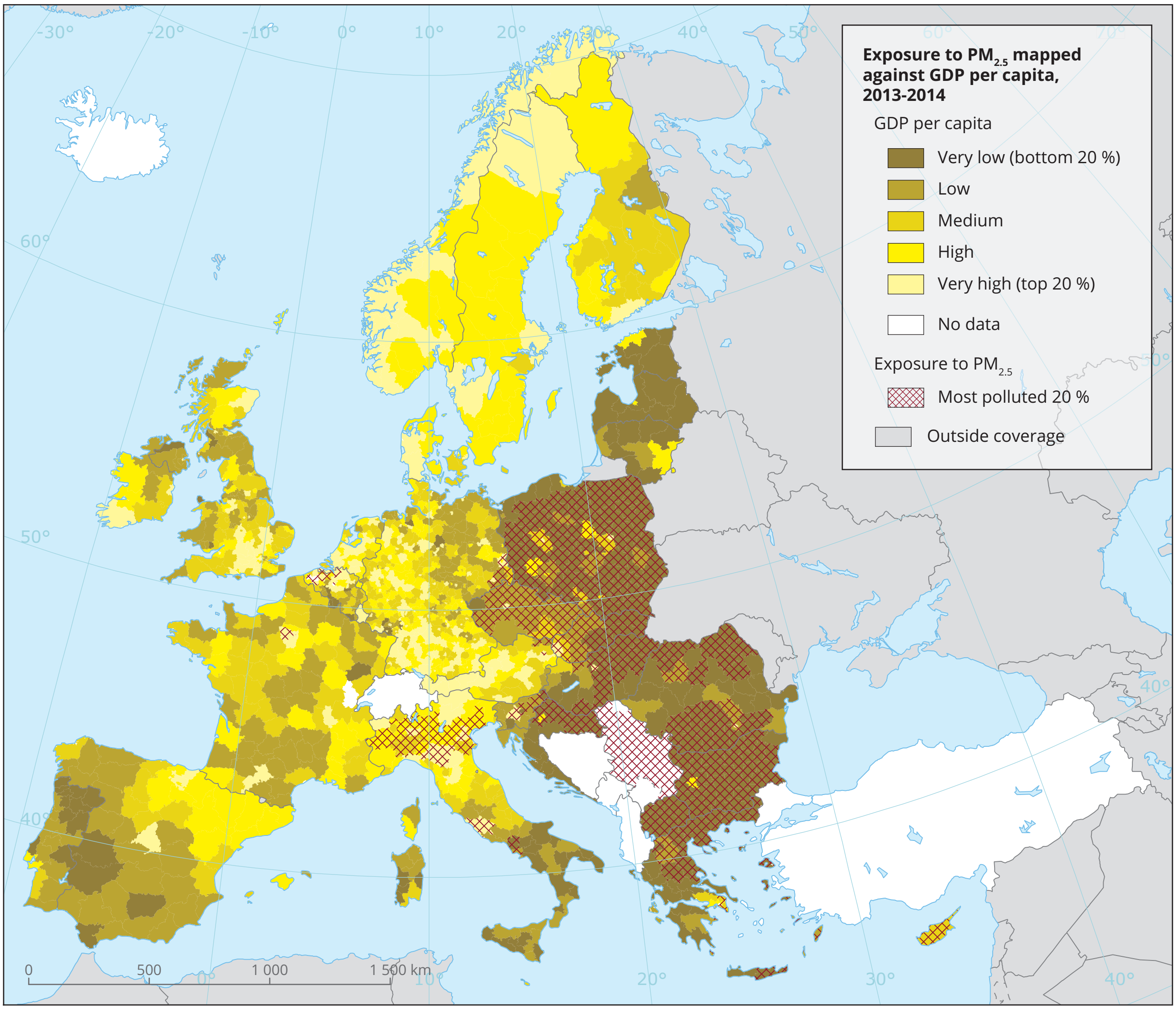
The most vulnerable 20 % of the larger (Nomenclature of Territorial Units for Statistics Level 2 — NUTS 2) regions, in relation to unemployment, household income and education levels, had $PM_{2.5}$ and PM_{10} pollution levels that, on average, were 1.3 to 1.5 times higher than those experienced by the least vulnerable 20 % of the regions. The spatial distribution of exposure to $PM_{2.5}$ and gross domestic product (GDP) per capita is illustrated in Map 4.4, which shows the spatial coincidence of poverty and pollution in eastern and south-eastern Europe. A factor driving this pattern is energy poverty, which is more prevalent in southern and central-eastern Europe. Poorer communities rely on the combustion of low-quality solid fuels, such as coal and wood, in low-efficiency ovens for domestic heating. This results in exposure to PM and PAHs, both indoors and outdoors (EEA, 2019c).

In contrast, the economic aspects of social vulnerability (GDP ([7]) per capita at NUTS 3 level and household income deprivation at NUTS 2 level) were only weakly associated with ozone exposure. Despite this, the poorest 20 % of smaller (NUTS 3) regions were exposed, on average, to ozone SOMO35 ([8]) levels that were 1.3 times larger than those experienced by the wealthiest 20 %. This is linked to warm climates driving ozone formation, with no causal link between poverty and ozone being suggested.

While some associations can be drawn at the larger NUTS 2 and NUTS 3 levels, there is a need for more regional, small-scale studies to assess the links between socio-economic status and air pollution at a finer spatial level.

([6]) The analysis focused on Nomenclature of Territorial Units for Statistics (NUTS) 2 and 3.
([7]) GDP is an indicator of economic activity. It is the value of all goods and services produced minus the value of any goods or services used during their creation.
([8]) SOMO35 is defined as the yearly sum of the daily maximum of 8-hour running averages over 35 parts per billion (ppb).

Map 4.4 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: EEA (2018a).

4.3 Environmental noise and health

Key messages:

- Noise is the second most important driver of the environmental burden of disease in Europe after air pollution.
- Long-term exposure to environmental noise is estimated to cause 12 000 premature deaths and contribute to 48 000 new cases of ischaemic heart disease per year in Europe.
- In total, 22 million people suffer chronic high annoyance and 6.5 million people suffer chronic high sleep disturbance due to noise.
- Roads are the main source of environmental noise, with 20 % of the EU population exposed to traffic noise levels that are harmful to health.
- As a result of aircraft noise, 12 500 school children suffer learning impairment in school. Children are more at risk of impacts on their cognitive development, have less well-developed coping strategies and less control over noise than adults.
- Evidence linking lower socio-economic status and exposure to noise is mixed, with associations influenced by local factors, such as property value in city centres.

Environmental noise is one of the top environmental risks to both physical and mental health and well-being in Europe (see Figure 4.6). This is reflected in the EU's Seventh Environment Action Programme (7th EAP), which guided European environmental policy up until 2020 and included the action to ensure that, by 2020, 'noise pollution in the Union has significantly decreased, moving closer to WHO-recommended levels' (EU, 2013a). However, the latest EEA assessment on noise in Europe indicates that the number of people exposed to high levels of noise has not decreased, with millions of people still exposed to noise levels that are harmful to their health (EEA, 2020a). This 7th EAP objective has therefore not been achieved. An overview of relevant policies is provided in Box 4.3.

4.3.1 Health impacts of noise pollution

Exposure to noise can lead to auditory and non-auditory effects on health. Through direct injury to the auditory system, noise leads to auditory effects, such as hearing loss and tinnitus (WHO Europe, 2018). This is frequently caused by loud work noise, loud music (e.g. from continuous high exposure to personal music devices and/or at music venues) or loud fireworks (WHO, 2004; WHO and ITU, 2019).

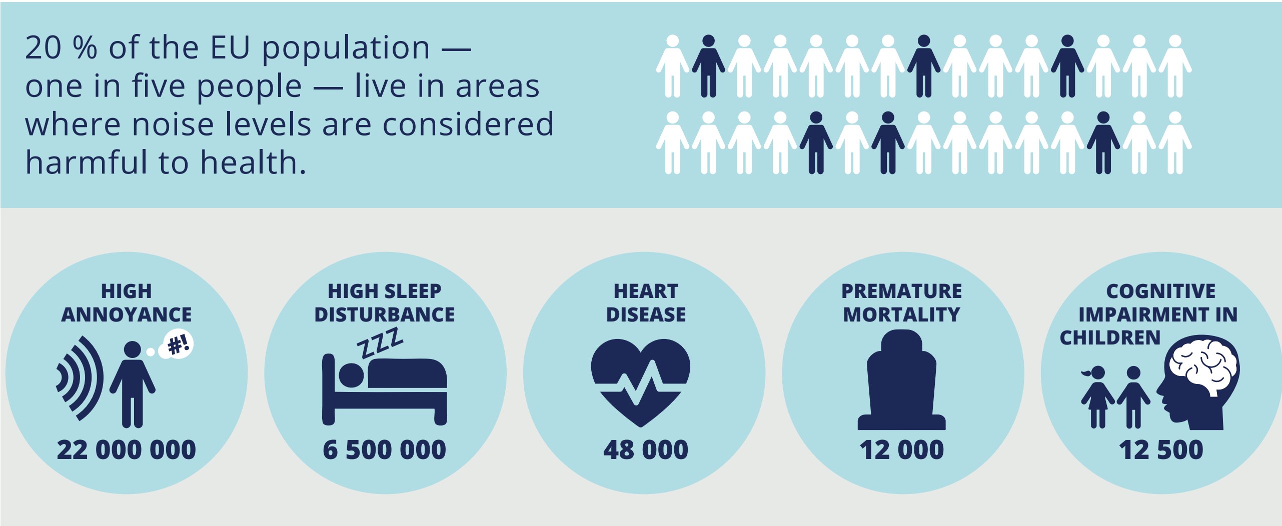
However, there are other effects that occur at levels far below those causing hearing impairment if exposure is long term. These are called non-auditory effects of noise (see Box 4.5) and are the result of psychological and physiological stress reactions (Basner et al., 2014). Repercussions of these stress reactions are extensive and include annoyance, poor sleep, cardiovascular and metabolic effects, and cognitive impairment in children (WHO Europe, 2018). While some studies have also found links between mental health and exposure to noise, there is a need to carry out significantly more research in this area, to determine the potential effects (Clarke and Paunovic, 2018).

Figure 4.7 illustrates how exposure to noise affects health and well-being. Within the population exposed to elevated levels of noise, stress reactions, sleep-stage changes, and other biological and biophysical effects may occur. These may, in turn, lead to a worsening of various health risk factors, such as blood pressure. For a relatively small part of the population, the subsequent changes may develop into clinical symptoms, such as insomnia and cardiovascular diseases.

The most recent EEA assessment of the health impacts of noise from roads, railways, aircrafts and industry in Europe found that noise contributes to 48 000 new cases of heart disease per year and 12 000 premature deaths (see Table 4.2). Over 21 million people suffer high annoyance due to noise, while nearly 6.5 million have their sleep disturbed. As a result of aircraft noise, 12 500 schoolchildren suffer learning impairments in school (EEA, 2019a).

Based on data from six European countries, Hänninen et al. (2014) estimated that the environmental burden of disease associated with transport-related noise is between 400 and 1 500 disability-adjusted life-years (DALYs) per million people, making it the second highest environmental burden of disease in western Europe,

Figure 4.6 Noise pollution exposure and impacts in Europe



Source: EEA (2020a).

Box 4.3 An overview of policies addressing environmental noise

Within the EU, the main instrument used to identify and enable action on noise pollution is Directive 2002/49/EC (EU, 2002), known as the Environmental Noise Directive (END). This requires Member States to publish both noise exposure maps and noise management actions plans on a 5-year basis. The END also recognises the need to preserve areas of good acoustic environmental quality, referred to as 'quiet areas', to protect the European soundscape.

Recently, the World Health Organization noise guidelines for the European region have been updated to better support the protection of human health from exposure to environmental noise. This resulted in new guideline values for road, rail and air traffic, and for wind turbines (WHO Europe, 2018).

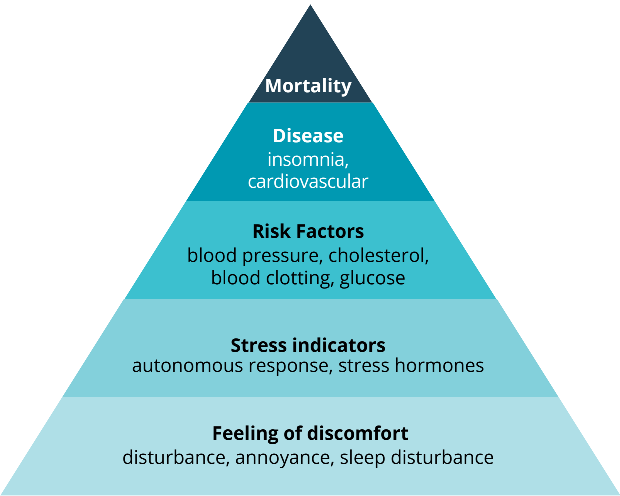
Box 4.4 Development of a comprehensive approach for the determination of non-auditory health impacts

The relationship between environmental noise exposure and non-auditory human health impacts is very complex and depends not only on basic measurements of the physical noise in an area but also on non-acoustic factors, such as attitudinal, situational and socio-demographic factors.

A report by the French Agency for Food, Environmental and Occupational Health and Safety (ANSES) (ANSES, 2013a) recommends that a number of additional non-acoustic determinants are taken into consideration, to fully account for the effects of environmental noise on human health, in addition to the underlying and measurable physical characteristics of the noise in question. These are split into two groups, as identified below, and should be incorporated into research on the health impacts of environmental noise, to develop more definitive relationships between exposure and non-auditory impacts.

Socio-demographic factors	Attitude factors
Gender, age, level of education, residential status (i.e. owner/tenant), professional dependence on the source of the noise, use of the noise source, personal history	Sensitivity to noise, attitude towards the source (fear, usefulness), ability to deal with the noise, having confidence in the actions of public authorities, satisfaction with the local environment, activities in progress

Figure 4.7 Pyramid of the health effects of noise



Source: Based on WHO (1972).

after air pollution from fine PM. Efforts to translate the health costs of noise into economic costs in the UK are described in Box 4.5.

4.3.2 Sensitivity of vulnerable groups

Relatively few studies have been conducted to investigate disparities in exposure to environmental noise in vulnerable groups. Those that have, for the most part, have focused on children. The assessment of the impacts of noise exposure is complicated by the fact that people living quite close to each other can experience substantially different levels of noise exposure. This is generally not the case with other environmental stressors, such as air pollution, through which larger spatial areas tend to be exposed to similar concentrations of a given pollutant. The potential impacts of noise exposure on a number of different vulnerable groups are presented below.

Age vulnerability

While there is a need for more studies in this area, there is already evidence of a relationship between noise exposure and a decline in children's cognitive ability. For example, aircraft noise was shown to impair reading and oral comprehension in children attending schools under flight paths (Clark and Paunovic, 2018). It is considered that, psychologically, children are poorer at appraising threats from environmental stressors and also have fewer well-developed coping strategies (Clark et al., 2013).

Noise originating from other modes of transport has also been shown to have an impact on children (Stansfeld and Clark, 2015). For example, a recent study in Norway suggested that road traffic noise has a negative impact on children's attention (Weyde et al., 2017). Lim et al. (2018) also reported that noise and noise sensitivity are negatively associated with the mental health of children and adolescents, particularly in low-income groups.

There is no evidence that elderly people are disproportionately affected by noise (van Kamp and Davies, 2013); however, there is evidence that older people are more at risk of suffering from cardiovascular effects due to noise (Tobias et al., 2014). Noise has also been found to affect middle age ranges more when annoyance and disturbance are considered (Van Gerven et al., 2009).

Noise-sensitive people

Noise-sensitive people are individuals who tend to have a specific discriminating sensitivity towards noise

Table 4.2 Estimated number of people suffering from different health outcomes due to environmental noise in 2017, EEA-33 (Turkey not included)

Health effect	Estimated number of people affected
High annoyance	21 868 500
High sleep disturbance	6 476 600
Ischaemic heart disease	48 000
Cognitive impairment in children	12 400
Premature mortality ([a])	12 100

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

Source: EEA (2020).

Box 4.5 The economic impact of noise exposure: a UK example

One way of quantifying the damage caused by noise exposure across Europe is in terms of the economic impact. Harding et al. (2013) conducted a study in the United Kingdom focusing on three health problems strongly associated with noise-induced high blood pressure, namely heart disease, stroke and dementia cases.

The team monitored noise levels at 1 160 sites across the country, between 2000 and 2001, and combined these data with information on the age and sex of UK residents, to calculate the added health problems from noise pollution exposure.

They used 'quality-adjusted life-years' (QALYs), which take into account quality of life, combining years spent living and years spent coping with a non-life-threatening illness. The researchers calculated the health impacts of noise exposure above 55 dB $L_{Aeq16hr}$ to cost EUR 1.34 billion per year (based on a value for 1 QALY of GBP 60 000).

Furthermore, these are simply intangible costs, arising from the loss of healthy life-years due to morbidity and mortality. If the study had considered the economic impacts of treatment, these figures would be much greater. For example, in the United Kingdom, in 2008, approximately 99 % of the total costs for dementia were attributable to the combined costs of healthcare and social and informal care, and less than 1 % of costs were attributable to morbidity and mortality (Harding et al., 2013).

and thus tend to be more annoyed by noise exposure than others. This highlights the subjective element of noise disturbance, as different individuals can exhibit different levels of annoyance to the same noise, which can be unrelated to their physical ability to hear sounds (Shepherd et al., 2010). This noise sensitivity can degrade the quality of life of individuals through increased annoyance and sleep disruption (Shepherd et al., 2010). Associations between noise sensitivity and various mental health-related factors, such as anxiety, depression, higher benzodiazepine usage and future psychiatric disorders, have also been reported (Lim et al., 2018).

Socio-economic status

Socio-economic status can also be associated with an individual's vulnerability to noise exposure. A broad review of the existing evidence of the links between social inequality and environmental noise exposure (Dreger et al., 2019) concluded that, while findings were mixed, studies that used indicators of material deprivation and deprivation indices found higher environmental noise exposure in lower socio-economic groups.

In the Netherlands, greater exposure to road and rail noise were linked to increased depressive symptoms in lower-education groups (Putrik et al., 2015). This has also been identified for self-reported sleep problems caused by neighbourhood noise (Arber et al., 2009). In addition, those living in more deprived locations in Southampton were found to have less access to quiet areas (Battaner-Moro et al., 2010). However, a Swiss study identified no direct link between socio-economic status and the risk of dying from a heart attack in areas exposed to aircraft noise; instead, it found that the length of time spent in a residence exposed to high levels of noise was the main factor increasing the risk of a heart attack (Huss et al., 2010). A study in London (Tonne et al., 2018) also found that inequalities in road traffic noise exposure were generally small. This reflects the fact that those from more affluent social groups may choose to live in areas more 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).

Eurostat also collects data on the percentage of households reporting noise from neighbours or the street. These data indicate that a higher percentage of lower income households report issues with noise from neighbours or the street. In 2017 and 2018, the percentages of lower income households reporting noise issues were 18.1 % and 18.8 %, respectively, while the percentages for higher income households were 14.4 % and 16.5%, respectively (Eurostat, 2019e).

The variations in the findings of different studies indicate that noise exposure is very much subject to local factors. As such, locally conducted small-scale studies can assess whether or not there is a relationship between noise exposure and socio-economic status (Dale et al., 2015, Dreger et al., 2019). As an example, a study on population exposure to noise in homes in Malta is provided in Box 4.6.

There are also differences between individual countries. For example, in Croatia, Greece, Poland and Romania people at risk of poverty were less likely to be subjected to noise from neighbours or the street than the general population. This is because a high share of people at risk of poverty in these countries live in rural areas (Eurostat, 2019f). In contrast, in countries where poverty is more concentrated in cities, such as Belgium, Germany and France, those at risk of poverty report higher levels of noise from the streets or neighbours.

A recent EEA assessment explored the links between social deprivation and noise exposure at a European level. It considered the proportion of people exposed to road noise of L_{den} ≥ 55 dB ([9]) and L_{night} ≥ 50 dB ([10]) (night noise levels) and socio-economic data in relatively large spatial units. The results must be interpreted carefully, as it was assumed that noise exposure was uniform across the spatial units for which the socio-economic data were available. In reality, exposure to noise is much more localised than exposure to air pollution, and ambient levels vary considerably across short distances.

For the most part, associations between noise and social vulnerability were much less clear than associations between air pollution and social vulnerability. There was found to be a relatively even distribution of the proportion of people exposed to L_{den} ≥ 55 dB and L_{night} ≥ 50 dB across the European regions. There were associations between the proportion of people exposed to noise and unemployment in urban audit cities and household income deprivation, suggesting that cities and regions containing poorer populations are more exposed to noise. It must be noted, however, that, across cities, there is a high variability in the percentage of people exposed in the different income categories, meaning that there are cities with relatively high exposure levels across all ranges of deprivation (EEA, 2018a).

4.3.3 Exposure to noise across Europe

Noise exposure

Unlike air pollution, in relation to which there can be complex relationships between the source and subsequent air quality over a wide area, noise pollution has the greatest impact near to its source. At a macro-level, the spatial distribution of road noise exposure has been found to show no large-scale patterns across Europe (EEA, 2018a). In addition, there was no systematic difference between urban and rural areas. This is likely because of data constraints, but it also potentially reflects the fact that, in rural areas, noise exposure may be high if dwellings are concentrated around roads with heavy traffic, while in city centres high noise areas can be seen as desirable places to live. In rural areas, sources of noise can also include farming activities (tractors, harvesters, animals).

In terms of sources of noise, the road transport network is the most widespread noise source, and this is true on an EU scale, a country scale and both inside and outside urban centres. It is estimated that 113 million people are exposed to traffic noise levels of at least 55 dB L_{den}, with 22 million exposed to railway noise, 4 million exposed to aircraft noise and less than 1 million exposed to industrial noise. Overall, this means that at least 20 % of Europeans are exposed to noise of at least 55 dB L_{den}, at which health effects can occur. Figure 4.9 shows the number of people exposed to noise above 55 dBL_{den} in the years 2007, 2012, and 2017, with an increase seen in exposure to noise from road, rail and air traffic in urban areas, and to noise from rail traffic in rural areas.

4.3.4 Quiet areas in Europe

Given the value of quiet areas for human health, as well as for biodiversity, it is important to identify and protect areas in Europe that are potentially quiet (EEA, 2016b). It is estimated that 18 % of Europe's rural land area is not likely to be affected by high levels of noise, while 33 % remains potentially adversely affected by noise pollution (EEA, 2016b).

The level of potential quietness is depicted using the Quietness Sustainability Index. The Index ranges from 0 to 1, with 0 implying a noisy area and 1 implying a potential quiet area (EEA, 2014). Map 4.5 shows the location of potential quiet areas in Europe. The northern part of Europe has the most potential quiet areas. Countries that have high population and transport network densities tend to have fewer potential quiet areas in the open countryside.

Quiet areas have been found to provide other benefits. For example, health-related quality of life is highest in quiet rural locations (Shepherd et al., 2013), and there is evidence that individuals suffering from illness recover faster in natural surroundings (Ulrich, 1984; Kaplan, 1995; Alvarsson et al., 2010).

([9]) L_{den} is a long-term average indicator designed to assess annoyance and defined by the Environmental Noise Directive. It refers to an A-weighted average sound pressure level over all days, evenings and nights in a year, with an evening weighting of 5 dB(A) and a night weighting of 10 dB(A). High noise levels are defined in the 7th EAP as levels above 55 dB L_{den}.

([10]) L_{night} is a long-term average indicator defined by the Environmental Noise Directive and designed to assess sleep disturbance. It refers to an A-weighted annual average night period of exposure. High noise levels are defined in the 7th EAP as levels above 50 dB L_{night}.

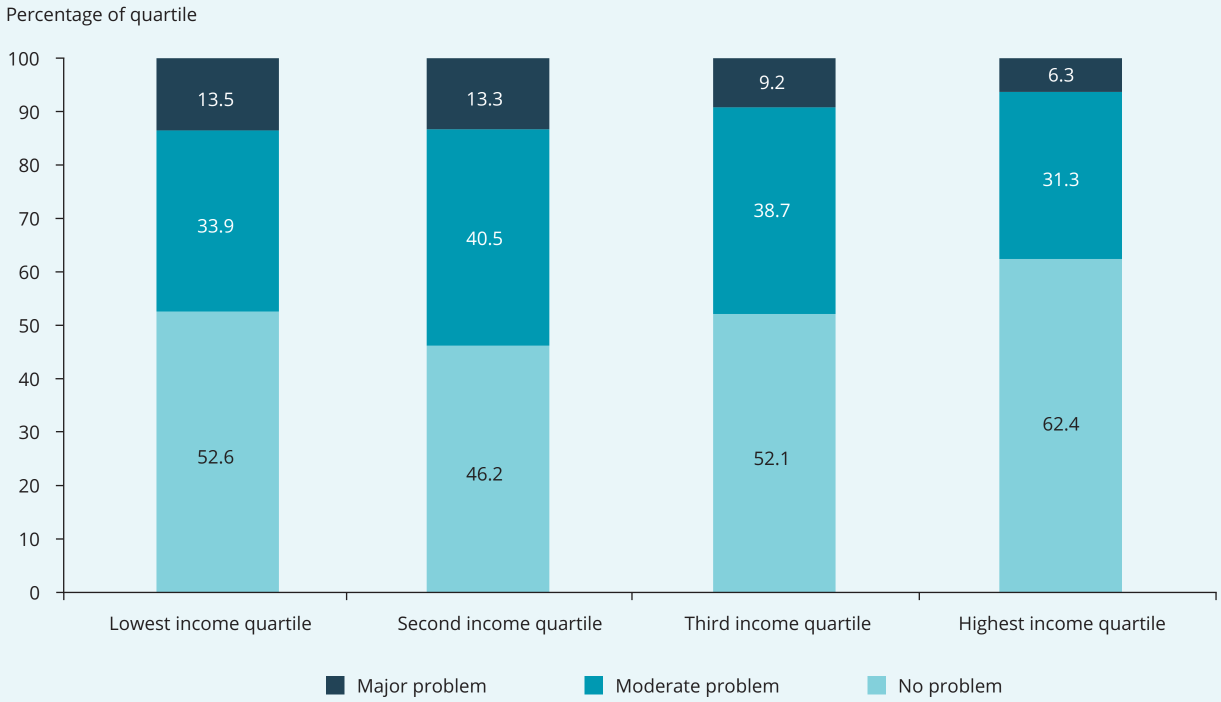
Box 4.6 Case study: population exposure to noise in homes in Malta

In 2011, 30.4 % of the Maltese population reported being exposed to noise in their homes — this is significantly higher than the EU average, of 19.8 %, for the same year.

An analysis of noise nuisance data based on income quartiles indicated that more than twice as many people in the lowest income quartile reported major noise problems when compared with the wealthiest quartile. People in the highest income quartile were more likely to have no problem with noise (62.4 %), compared with the lowest quartile (52.6 %), as shown in Figure 4.8.

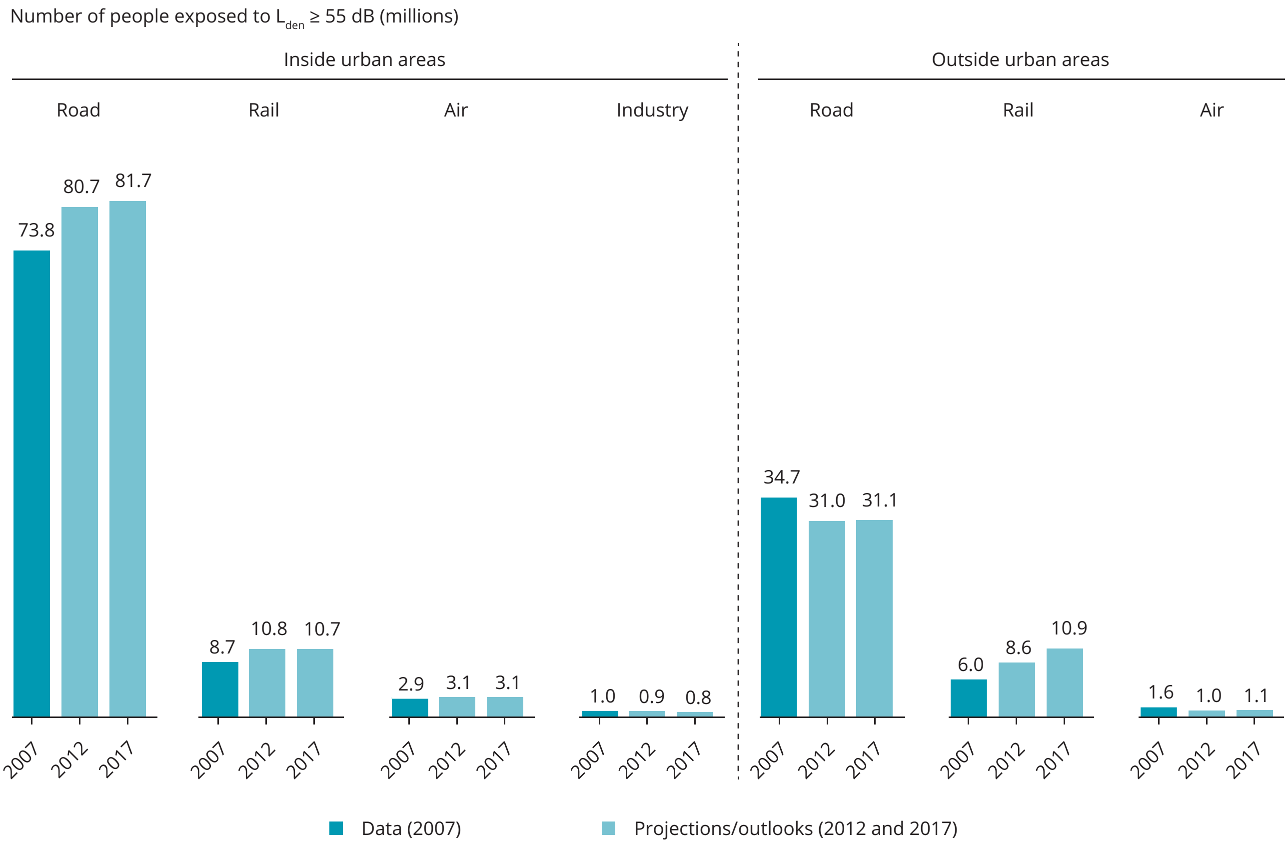
The same study also found that older residents were more likely to be affected than younger people, with 13.7 % of those aged over 65 years perceiving noise as a neighbourhood problem, compared with 5.9 % of 18- to 24-year-olds.

Figure 4.8 Percentage of the population reporting noise problems by income quartile during the period 2011-2012



Source: Ministry for Health (Malta) (2013).

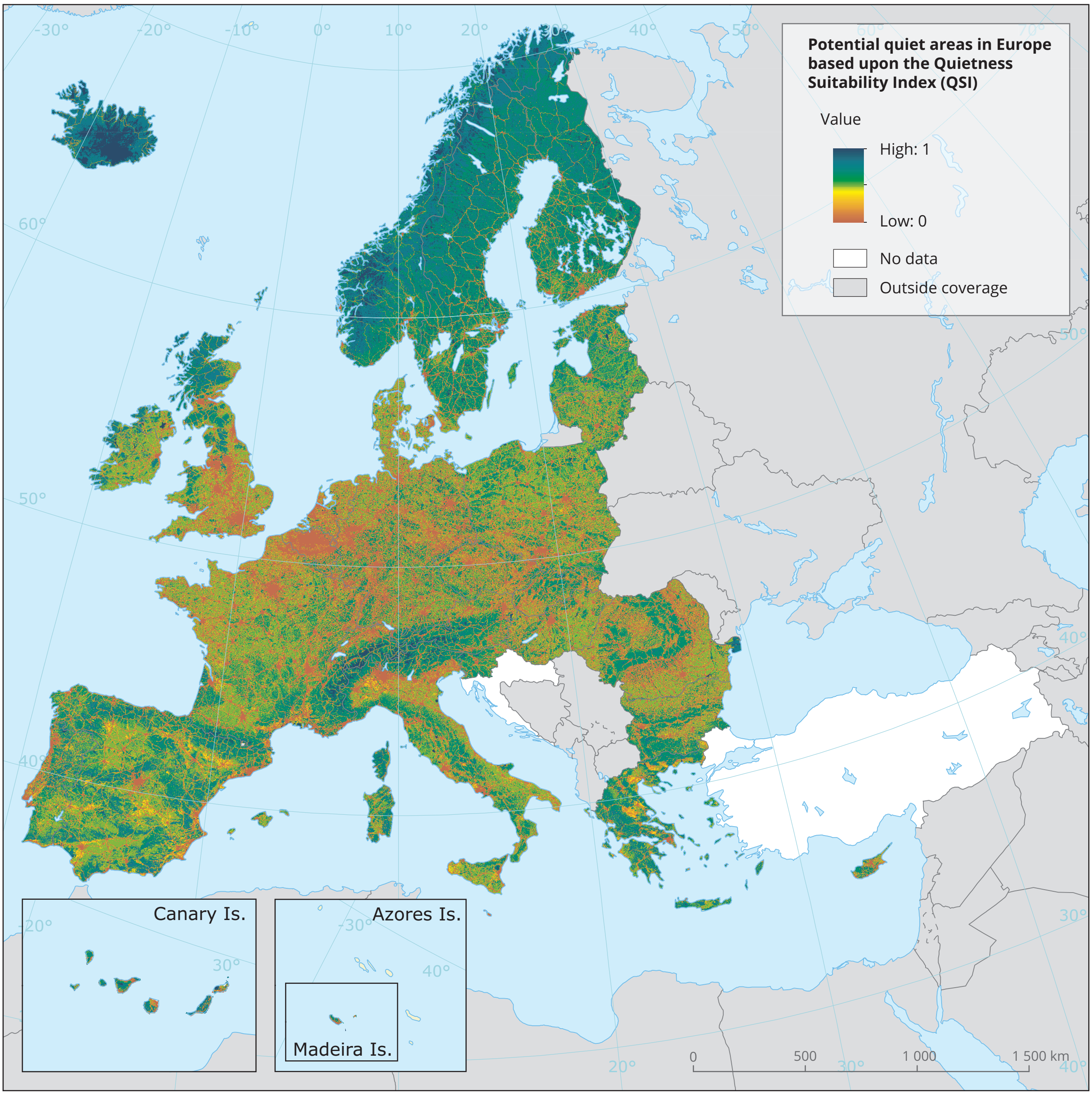
Figure 4.9 **Number of people exposed to noise at levels that affect health in 2007, 2012 and 2017, EEA-33 (Turkey not included)**



Note: There are comparability issues between 2007 and the other reporting years because of different reporting requirements. There may be comparability issues between 2012 and 2017 because of a lack of common assessment methods or incomplete reporting of exposure assessments. As a result of the gaps in the reported data, a gap-filling method was used to estimate the number of people exposed to high noise levels in 2012 and 2017, introducing a degree of uncertainty.

Source: EEA (2019a).

Map 4.5 **Potential quiet areas in Europe based on the Quietness Suitability Index**



Note: The quietness suitability index provides a measure of the noise level, with 0 implying that the area is likely to be noisy and 1 implying that the area is potentially quiet.

Source: EEA (2016b).

4.4 Climate change and health

Key messages:

- Climate change contributes to the burden of disease and premature deaths in Europe.
- Direct health effects include death, injury and the increased risk of food- and water-borne disease, resulting from extreme temperatures, floods and forest fires.
- Indirect impacts result from changes in the distribution of climate-sensitive vector-borne diseases and allergens, reductions in agricultural productivity and contaminated water sources.
- Heatwaves are the deadliest extreme weather event in Europe. The 2003 heatwave caused 70 000 premature deaths in Europe. City dwellers are more exposed to extreme heat because of the heat island effect.
- Floods caused over 8 000 deaths in the 33 EEA member countries between 1980 and 2016.
- The elderly, the sick, children, pregnant women and socially deprived communities are more vulnerable to climate change impacts because of increased sensitivity and reduced resilience.
- Socially deprived communities are more exposed to extreme temperatures and floods because of the poor quality of their housing.

Climate change is increasing the frequency and severity of many types of extreme weather and climate-related events, both globally and across Europe (IPCC, 2014). Nearly all extreme weather events have increased in severity, duration and/or extent in Europe (EEA, 2017b), including heatwaves, heavy precipitation, hail, severe flood events, windstorms, landslides, droughts, forest fires, alpine avalanches and high coastal waters (EEA, 2017a). In Europe, 2014, 2015 and 2018 were the warmest 3 years on record (EEA, 2019d), and recent summer temperatures lie significantly outside the range of expected natural variability (Luterbacher et al., 2016). The summer of 2019 also saw record-breaking heatwaves across Europe.

Climate change poses major risks to health, leading to injuries and increasing the risk of both communicable and non-communicable diseases. Conditions such as extreme heat, wildfires and floods pose a direct risk to health, while longer term risks, such as changes in the distribution of infectious diseases and allergens, are mediated through changes in ecosystems and socio-economic systems (EASAC, 2019).

The elderly, people with ill health, pregnant women, children and migrant and marginalised populations are most vulnerable to the health impacts of climate change. Urban areas with dense populations are also particularly vulnerable, with climate change heavily influencing the microclimates of cities. During heatwaves, the effect of heat can be exacerbated in cities, and this is particularly problematic in regions where buildings are designed for cold environments (EEA, 2016c). Higher mortality rates are seen in dense urban areas, as a result of the heat island effect. Climate change also contributes to health risks in the indoor environment, including high temperatures, poor indoor air quality, increased allergens and pathogens, flood damage and water contamination (Vardoulakis et al. 2015). Flooding, water scarcity and droughts also pose threats to cities.

Under the worst-case, high-emission (RCP8.5) ([11]) scenario, extreme heatwaves considerably stronger than those that occurred in 2003 are projected to occur as often as every 2 years in the second half of the 21st century (EEA, 2017b). The frequency and intensity of all extreme weather events is expected to increase this century. Oceans and marine environments, coastal zones, freshwater systems and terrestrial ecosystems will also be affected (EEA, 2017a).

An overview of climate change adaptation policies is provided in Box 4.7. Regarding emissions of greenhouse gases, the European Green Deal set out the Commission's ambition to make Europe the first climate-neutral continent by 2050. In March 2020, the Commission proposed a European Climate Law

([11]) Scenarios to support climate change research and assessments are called representative concentration pathways (RCPs). The RCPs provide a consistent set of trajectories for future atmospheric composition and land use change up to the year 2100. The four RCPs are named from RCP2.6 to RCP8.5, according to their approximate radiative forcing level in the year 2100.

(EC, 2020f), which includes a legally binding target of net zero greenhouse gas emissions by 2050, aiming to protect health, food systems and ecosystems and to increase social resilience to climate change.

4.4.1 Health impacts of climate change

The effects of climate change on human health are wide ranging. Climatic changes, such as heatwaves and increased precipitation, have an impact on human health, both directly or indirectly (McMichael, 2013) and exacerbate problems that already exist (EEA, 2016c; EEA, 2017a). Direct impacts include traumatic injury or death, post-traumatic stress and disease risk. Indirect health impacts result from socio-environmental changes, such as reduced food yields jeopardising nutritional status and causing displacement, infrastructure damage creating physical hazards and changes in the distribution of climate-sensitive diseases.

In terms of deaths attributable to climate change, during the period 1980-2017, climate- and weather-related events caused 90 325 additional deaths across the 33 EEA member countries (EEA-33). Heatwaves are the deadliest type of extreme weather across Europe as a whole, with 68 % of additional deaths (77 637) attributed to heatwaves over the same period (EEA, 2019e). In eastern Europe, cold events and storms cause the highest number of excess deaths (CRED, 2019). In terms of the economic impacts of climate change, the total reported economic losses caused by weather- and climate-related extremes in the EEA member countries during the period 1980-2017 amounted to approximately EUR 453 billion, with over a third associated with flooding (EEA, 2019b).

Deaths attributable to climate change in Europe are predicted to increase significantly, with a clear geographical north-south divide, whereby countries in southern Europe will be more affected by global warming than those in the north and will see more heat-related deaths, water stress, habitat loss, energy demand for cooling and forest fires. The Mediterranean area appears to be the most affected by climate change (Ciscar et al., 2018).

Extreme temperatures

Temperature affects human well-being and mortality, with both cold and heat having an impact on public health in Europe.

Heat or hot weather that lasts for several days, often referred to as a 'heatwave', can result in a rise in mortality and morbidity (WMO and WHO, 2015). Exposure to heat can cause heat fatigue, heat stroke or heat stress, and can worsen existing health issues, such as respiratory and cardiovascular diseases and kidney problems (Åström et al., 2013; Analitis et al., 2014; Breitner et al., 2014). In addition, hot weather has synergistic effects with air pollution,

Box 4.7 Policies addressing climate change adaptation

The European Commission published an EU climate change adaptation strategy in April 2013, with three main objectives (EC, 2019g):

- to promote action by Member States by encouraging all Member States to adopt comprehensive adaptation strategies and by providing funding to help them develop their adaptation capacities and take action; to support adaptation in cities by launching a voluntary commitment based on the Covenant of Mayors initiative (since 2015, the Covenant of Mayors for Climate and Energy) (Covenant of Mayors for Climate and Energy, 2019);

- to carry out 'climate-proofing' action at the EU level by further promoting adaptation in key vulnerable sectors, such as agriculture, fisheries and cohesion policy, by ensuring that Europe's infrastructure is made more resilient and by promoting the use of insurance against natural disasters and disasters caused by human activity;

- to ensure better informed decision-making by addressing gaps in knowledge on adaptation and by further developing the European climate adaptation platform, Climate-ADAPT (Climate-ADAPT, 2019).

The adaptation strategy has been evaluated, with lessons learnt and reflections on improvements put forward. The evaluation calls on EU cities to have adaptation plans in place to protect citizens from both extreme and slow-onset climate hazards. The plans should cater for the vulnerabilities of certain communities and the different risks faced by the very diverse regions of the European continent (EC, 2018b).

An increasing number of EEA member countries have adopted national adaptation strategies, and several have developed and are implementing national adaptation action plans. Strategies and actions have also emerged in many cities and in transnational regions across Europe, including the Baltic Sea and the Carpathian and Alpine regions.

compounding health impacts (De Sario et al., 2013). Heat-related problems are greatest in cities, where population density is high and where the urban heat island effect plays a role in maintaining high temperatures.

In Europe, most deaths related to extreme weather are attributable to heatwave events. As shown in Map 4.6, from 1990 to 2016 the greatest numbers of fatalities due to high temperatures were seen in western and southern Europe. However, these data are skewed by the heatwave of 2003, when 70 000 excess deaths were reported across Europe (Robine et al., 2008).

Without the implementation of further adaptation measures, heat-related mortality is predicted to increase. Under the high-emissions global warming scenario ([12]), there could be an additional 132 000 deaths per year in the EU due to heatwaves by the end of the century, an increase by a factor of 50 compared with present heatwave mortality. Most of these additional deaths are predicted to occur in the central European regions and southern Europe. Under the 2 °C scenario, the additional deaths per year are predicted to be 58 000 for the period 2025 to 2055 (Ciscar et al., 2018).

Climate change is also projected to drive increases in hospital admissions in Europe because of heat-related respiratory diseases, from 11 000 admissions (0.18 %) during the period 1981-2010 to 26 000 (0.4 %) during the period 2021-2050. Again, both the current number of hospital admissions and the projected increases due to climate change are largest in southern Europe (Aström et al., 2013).

Long warm and dry periods increase the risk of forest fires, bringing about severe impacts on the health of surrounding populations, including death, injury and cardiovascular and respiratory illnesses due to air pollution (Analitis et al., 2012). The length and severity of the fire seasons are increasing in the Mediterranean region and southern Europe. Predictions suggest that the total burnt area of Europe will double in the 21st century (Ciscar et al., 2014).

Another less highlighted risk posed by increasing temperatures is the release of toxic chemicals, such as mercury, from melting permafrost (Schuster et al., 2018). Increasing surface water temperatures may accelerate the generation and bioaccumulation of methylmercury and persistent organic pollutants in fish, potentially affecting the health of people consuming these fish (Dijkstra et al., 2013). An additional risk of melting permafrost is exposure to diseases assumed to be contained, as described in Box 4.8.

Extreme cold can also significantly affect human health, with cold-related deaths primarily caused by cardiovascular and respiratory diseases. Low indoor temperatures 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 disease and migraines, as well as depression and anxiety (WHO Europe, 2012). At the same time, exposure to persistent moderately low temperatures affects health more than extremely low temperatures, which only marginally contribute to overall excess winter mortality.

As shown in Map 4.6, the highest numbers of fatalities from low temperatures are seen in eastern and southern Europe. Ebi and Mills (2013) also confirm that mortality due to low temperatures is highest in warmer countries, while in many countries with colder climates excess winter deaths are less pronounced or absent. Possible drivers include housing quality, energy affordability and the population's acclimatisation to and preparedness for lower temperatures.

As a result of milder winters as our climate changes, it is estimated that, by the 2080s, cold-related mortality will have decreased. However, the positive health impacts are not expected to outweigh the negative health effects of climate change (McMichael et al., 2012).

Drought

The severity and frequency of meteorological and hydrological droughts have increased in parts of Europe, in particular in south-western and central Europe. From 2006 to 2010, on average 15 % of the EU territory and 17 % of the EU population were affected by meteorological droughts each year. Under severe drought conditions, impacts on public water supply and water quality are likely in more populated regions of Europe, such as central France (Stahl et al. 2016).

Large increases in the frequency, duration and severity of meteorological and hydrological droughts are predicted to occur in most of Europe during the 21st century, except for northern European regions. The greatest increase has been predicted for southern Europe, increasing competition between different water users, such as agricultural, industry, tourism and household users (EEA, 2019f). The development of drought management plans helps to alleviate the worst impacts of extended droughts. For example, in Spain the development of such plans is required for all water supply systems serving more than 20 000 people (Hervás-Gámez and Delgado-Ramos, 2019).

([12]) RCP8.5 — under this scenario, projections of the level of global warming exceed 3 °C warming around 2070 and continue rising thereafter.

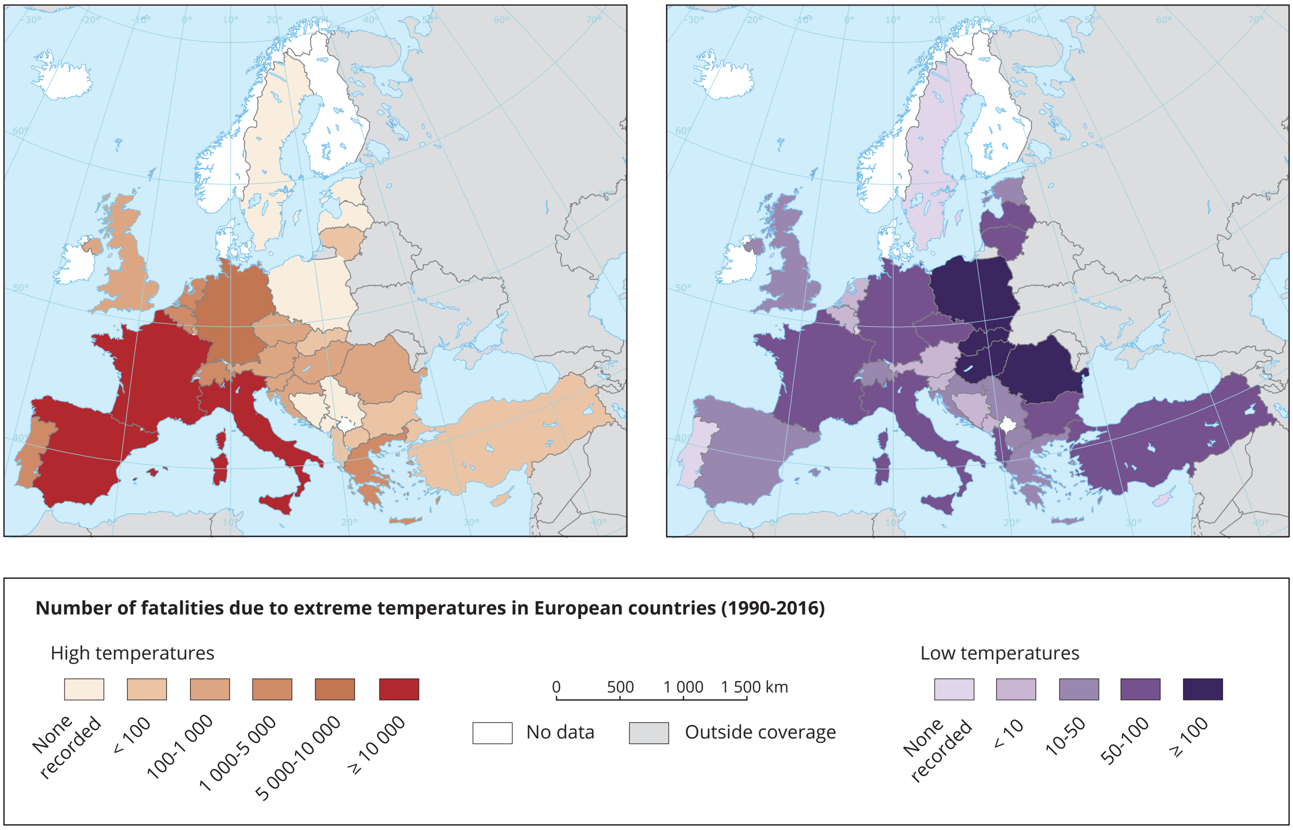
Box 4.8 Melting permafrost and anthrax

In August 2016, in a remote corner of the Siberian tundra — in a place called the Yamal Peninsula — an outbreak of anthrax killed a young boy and hospitalised at least 20 other people.

The source of this bacterial infection initially perplexed scientists, but a theory soon emerged that attributed this outbreak to the melting of the permafrost in this area. The melting had led to the defrosting of a reindeer carcass from over 75 years ago, which had been infected with anthrax. After the thaw, the bacteria, which had been preserved in the frozen ice, were released into nearby water systems and contaminated both human and animal drinking water (BBC, 2017).

There is a risk that, with continued permafrost melting, the vectors of potentially deadly diseases considered to be contained could see a resurgence (Revich and Podolnaya, 2012).

Map 4.6 Number of fatalities due to extreme temperatures across Europe (1990-2016)



Source: EEA (2019d).

Floods

Melting ice and a rise in sea surface temperatures have led to rising sea levels, which are predicted to lead to an increase in tidal flooding, while more frequent heavy precipitation is predicted to contribute to increased surface and fluvial flooding. Floods resulted in over 8 000 deaths in the EEA-33 between 1980 and 2016 because of drowning or injuries (EEA 2017). Map 4.7 shows the number of deaths related to flooding in each EEA member country and cooperating country for the period 1991-2015, normalised by their population. The largest numbers are found in south-eastern Europe, eastern Europe and central Europe.

Floods also affect people after the event through displacement, the destruction and degradation of homes, water shortages and financial losses (EEA, 2017a). Floods also disrupt the delivery of services, including healthcare, safe drinking water, sanitation and transport, generating indirect risks to health.

For example, floods bring an increased risk of infection from water-borne diseases, such as leptospirosis (Picardeau, 2013). People living in buildings that have been flooded are more at risk of infection, since humidity fosters the growth of microorganisms (Menne and Murray, 2013).

The stress that flood victims feel can affect their mental health for a long time after the event (Stanke et al., 2012; Fernandez et al., 2015). Up to three quarters of people affected by a flood have experienced mental health effects (Menne and Murray, 2013).

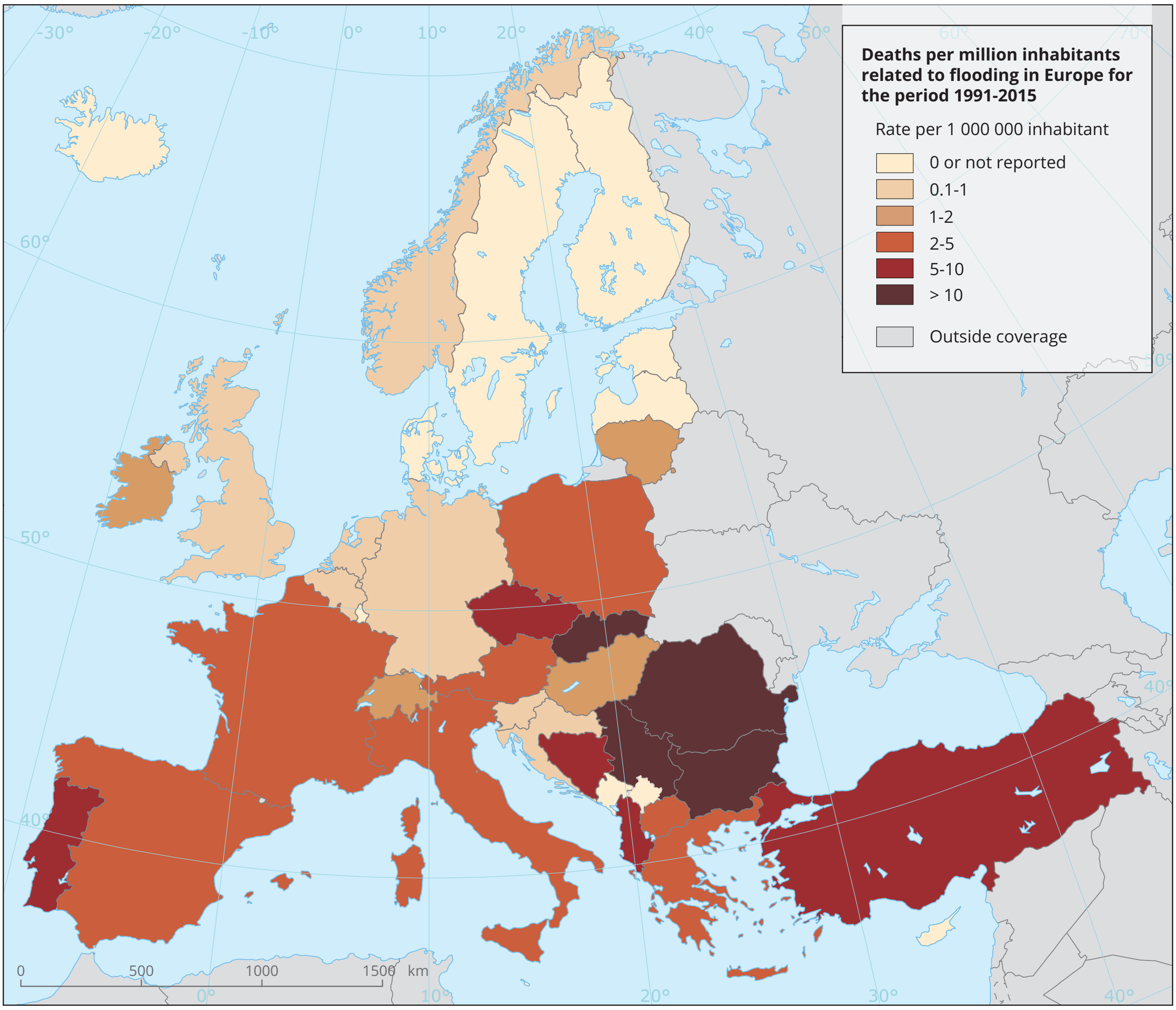
Floods may have unexpected impacts, by mobilising chemicals in the environment through releases from landfills or by remobilising pollutants deposited in soils and silt. One example is heightened human exposure to mercury as a result of increased soil erosion from flooding (Krabbenhoft and Sunderland, 2013).

In the absence of adaptation measures, projected increases in extreme precipitation events and sea level would substantially increase the health risks associated with river and coastal flooding in Europe (EEA, 2017a).

Vector-borne diseases

Vector-borne diseases are transmitted by carriers, such as insects or rodents, either between humans or from animals to humans. Climate change is projected to induce substantial shifts in the geographical and seasonal distribution of vectors and their associated diseases in Europe (Semenza and Menne, 2009) and might enable the establishment of exotic diseases currently not present on the continent (Randolph and Rogers, 2010).

Map 4.7 Number of European deaths related to flooding per million inhabitants, 1991-2015



Source: EEA (2017a) based on WHO (2016).

Box 4.9 Efforts to monitor changes in the distribution of vectors

European activities

At the European level, the European Centre for Disease Prevention and Control assesses the effects of climate change on infectious diseases and has established a pan-EU network dedicated to vector surveillance, known as VBORNET ([a]). The network undertakes targeted entomological collections in specific vector habitats to fill knowledge gaps.

Monitoring mosquitos and vector-borne diseases in Croatia

The appearance of dengue fever in 2010 and the West Nile virus in 2012 in Croatia signalled an increase in the potential for vector-borne diseases. Croatia saw a significant peak in vector-borne diseases in 2012 and 2013, coinciding with higher mean annual air temperatures. Cases were reported for malaria, dengue, chikungunya and West Nile meningoencephalitis. In 2016, the Croatian Institute for Public Health started the systematic monitoring of invasive mosquito species. Monitoring in 2017 confirmed the presence of the Asian tiger mosquito, a vector of chikungunya, dengue and Zika, and the Japanese mosquito, a vector of dengue and chikungunya. These data feed into an early warning system for vector-borne diseases, informing measures to control their distribution, including disinfection and public awareness raising.

Note: ([a]) VBORNET — European Network for Arthropod Vector Surveillance for Human Public Health (http://www.vbornet.eu).

Source: Private communication from the Croatian Institute for Public Health.

For example, climate change is regarded as the principal factor driving the expansion of the tick species *Ixodes ricinus* — the vector of Lyme borreliosis and tick-borne encephalitis in Europe — to higher latitudes and altitudes. Shifts in the distribution of *Ixodes ricinus* towards more northerly regions are projected.

The Asian tiger mosquito, *Aedes albopictus*, transmits the dengue, chikungunya and Zika viruses, as well as dirofilarial worms, and has substantially expanded its range in recent years, thought to be aided by climate change. Several outbreaks of these viral diseases have been reported in Europe (EEA, 2017a). Travellers returning from warmer climes may carry these diseases and introduce them into the local vector population, initiating an outbreak. The climatic suitability for *Aedes albopictus* is expected to increase in places where the climate is projected to become warmer and wetter, such as in the south-east region of the United Kingdom (Medlock and Leach, 2015), the Balkans and central Europe. In contrast, suitability decreases in places where the climate is predicted to become drier, such as in some regions of Spain and Portugal (Caminade et al., 2012).

Other examples include predictions of a progressive increase in the distribution across southern and eastern Europe of the West Nile virus transmitted by mosquitos (Semenza et al., 2016), and a considerably broader distribution across Europe of species of sandflies with the potential to act as vectors for leishmaniosis (Trájer et al., 2013). Box 4.9 outlines efforts to monitor disease-vectors at European level and in Croatia.

Water- and food-borne diseases and health

With the notable exception of non-cholera Vibrio infections, it is difficult to attribute specific outbreaks of water- and food-borne diseases in Europe to climate change. At the same time, pathogens are sensitive to climate-related factors, with changes in these factors known to affect the risks of certain food- and water-borne diseases.

Increased air and water temperatures accelerate the growth rates of pathogens, including bacteria, viruses and parasites. For example, since 1980 the number of *Vibrio* infections, which can be life-threatening, has increased substantially in the Baltic Sea states. This is linked to increases in sea surface temperatures, which provide ideal conditions for *Vibrio* blooms. The unprecedented number of *Vibrio* infections in 2014 is linked to the 2014 heatwave in the Baltic region (Vezzulli et al., 2016).

Flooding can contaminate drinking water sources and disrupt water treatment and sanitation systems (Semenza et al., 2012). Drought conditions can also reduce the effectiveness of water treatment facilities (Tran et al., 2017). Evidence of the response of pathogens to climate factors is presented in Table 4.3.

4.4.2 Vulnerable groups

While all people in Europe will be affected by climate change, certain people in society are more vulnerable

Table 4.3 Human pathogens that respond to climate factors

Pathogen	Health impacts	Response to climate factors
Vibrio	*Vibrio* species cause gastroenteritis. Infection occurs through the consumption of seafood. On rare occasions, *Vibrio* infections can cause severe necrotic ulcers, septicaemia and death in susceptible individuals exposed to contaminated marine environments during bathing.	Elevated levels of non-cholera *Vibrio* species infections have been observed during extended hot summer seasons, with water temperatures above 20 °C in the Baltic Sea and the North Sea.
Campylobacter	Campylobacteriosis is the most common bacterial cause of diarrhoeal disease in Europe. Infection occurs via contaminated food.	More cases of campylobacteriosis are seen during the summer months, associated with the ambient temperature that precedes the diagnosis of cases by 10 to 14 weeks.
Salmonella	Salmonellosis is the second most commonly reported gastrointestinal infection. Exposure occurs via contaminated food. Infection occurs through the consumption of contaminated food of animal origin, mainly eggs, meat, poultry and milk. Overall, the incidence of the infection has declined steadily in Europe because of effective control measures in poultry production.	An increase in weekly temperature has been associated with an increase in salmonellosis. Public health interventions can counter the impact of warmer temperatures. Extreme precipitation events that result in faecal contamination events have also been associated with salmonellosis.
Norovirus	*Norovirus* is the most common cause of viral diarrhoea in humans. The incidence of norovirus shows pronounced winter seasonality. Infection occurs via oral contact with faecal matter or vomit from an infected person. Food or drink may become infected via food handling.	Food-borne *Norovirus* outbreaks have been linked to climate and weather events. Heavy rainfall and floods can lead to waste water overflow, contaminating shellfish farming sites. Peaks in diarrhoea incidence have been linked to the magnitude of rainfall. Flood water was associated with a norovirus outbreak in Austria.
Cryptosporidium	Cryptosporidiosis is an acute diarrhoeal disease caused by intracellular protozoan parasites, *Cryptosporidium* species. Transmission occurs through the faecal-oral route via contaminated water, soil or food products. The most common exposure routes are contaminated drinking water and contaminated recreational water.	The concentration of *Cryptosporidium* oocysts in river water increases significantly during rainfall events. Heavy precipitation can result in the persistence of oocysts in the water distribution system and their infiltration into drinking water reservoirs. Infections following heavy rainfall have been seen in Germany and Sweden.

Source: Information is drawn from EEA (2017a). For additional details and references, see the source report.

because of their age, poor health or social deprivation. The Intergovernmental Panel on Climate Change (IPCC) definition of vulnerability is 'the propensity or pre-disposition to be adversely affected' (IPCC, 2014). Vulnerable people may be more sensitive to the health impacts of high or low temperatures and less able to access healthcare services for treatment. Certain groups are more exposed to extreme weather events because of the poor quality of their local environment and/or living conditions. Finally, poorer people may be less able to protect themselves from extreme weather events or afford solutions that could reduce their exposure in the long term, making them less resilient to the risks posed by climate change.

Why are certain groups more sensitive to the health impacts of climate change?

Generally, the elderly are the most vulnerable to the effects of heat because of poorer physical health (Josseran et al., 2009). Elderly people suffering from dementia, Parkinson's disease or Alzheimer's disease may be less able to keep themselves cool, while certain medications can cause dehydration. The elderly are also more susceptible to cold spells than other age groups (Ryti et al., 2015) and more likely to live in poor-quality housing. Older people often live alone and are less able to take action to protect themselves from environmental stressors (Koppe et al. 2004). Regarding floods, neurological conditions can affect both how a person perceives danger and their ability to respond (DEFRA, 2012). Higher levels of mortality occur among the elderly during floods because of hypothermia and heart problems (Green et al., 1994; Vardoulakis and Heaviside, 2012). Overall, older people experience more severe stress and mental health implications as a result of floods than the general population (Menne and Murray, 2013).

At the other end of the demographic scale, children are highly susceptible to dehydration and heat stress because of their greater body surface area to volume ratio (Stanberry et al., 2018). Children are more likely to be affected by respiratory disease, renal disease, electrolyte imbalance and fever during heatwaves (Xu et al., 2014). Heatwaves have also been shown to exacerbate the effects of allergens and air pollution (Stanberry et al., 2018), which impact children more severely than adults because of their underdeveloped respiratory and immune systems and relatively high rates of respiration. Children living in cold homes are also at greater risk of respiratory problems because of the likely development of moulds (WHO Europe, 2012) and are thought to be more at risk of mental health and disease impacts from flooding (ETC/CCA, 2018). Flooding has been associated with increased mental health and behavioural problems in children in the Netherlands and Poland (Jakubicka et al., 2010), as well as increases in the incidence of a range of diseases (Ahern et al., 2005).

Individuals with a poor health status are also more susceptible to health risks during heat extremes (Wolf et al., 2015), with chronic health problems more prevalent among the poor.

Why might vulnerable groups face increased exposure to climate change impacts?

Specific groups may face increased exposure to extreme temperatures, floods or droughts because of where they live, the quality of their housing and their ability to protect themselves from exposure to stressors. Single-level properties favoured by older people (Pannell and Blood, 2012) mean that older people are unable to retreat to higher floors if their home is flooded. Cold and damp housing conditions in the aftermath of flooding increases the incidence and severity of some illnesses in children (Marmot Review, 2011).

Differences in the exposure of people to extreme temperatures are to a great extent driven by variations in people's ability to maintain comfortable temperatures in their home, which varies from country to country, as shown in Map 4.8.

People's ability to their keep homes at a comfortable temperature is linked to energy poverty, including the energy efficiency of housing and the affordability of energy (WHO, 2012). Bulgaria, Greece, Malta and Portugal have high proportions of people affected by high summer temperatures. Importantly, the proportion of the general population unable to keep their home comfortably cool in summer in Europe is higher than that unable to keep their home warm in winter (WHO Europe, 2012). This suggests that heat may be a growing problem as the climate changes.

The problem of heat exposure is greatest in cities. Dense populations and demographic shifts towards elderly populations in many European countries lead to increased vulnerability, while the urban heat island effect increases the frequency and intensity of exposure and can have an impact on both outdoor and indoor air quality (Buscail et al., 2012). Temperatures in European city centres can be up to 9 °C higher than in the surrounding areas (Tzavali et al., 2015) and, as a result, urban areas may experience twice as many heatwave days as surrounding rural areas (Hooyberghs et al., 2015). The urban heat island effect is stronger in northern European cities, while in southern Europe rural-urban temperature differences are less extreme (Ward et al., 2016).

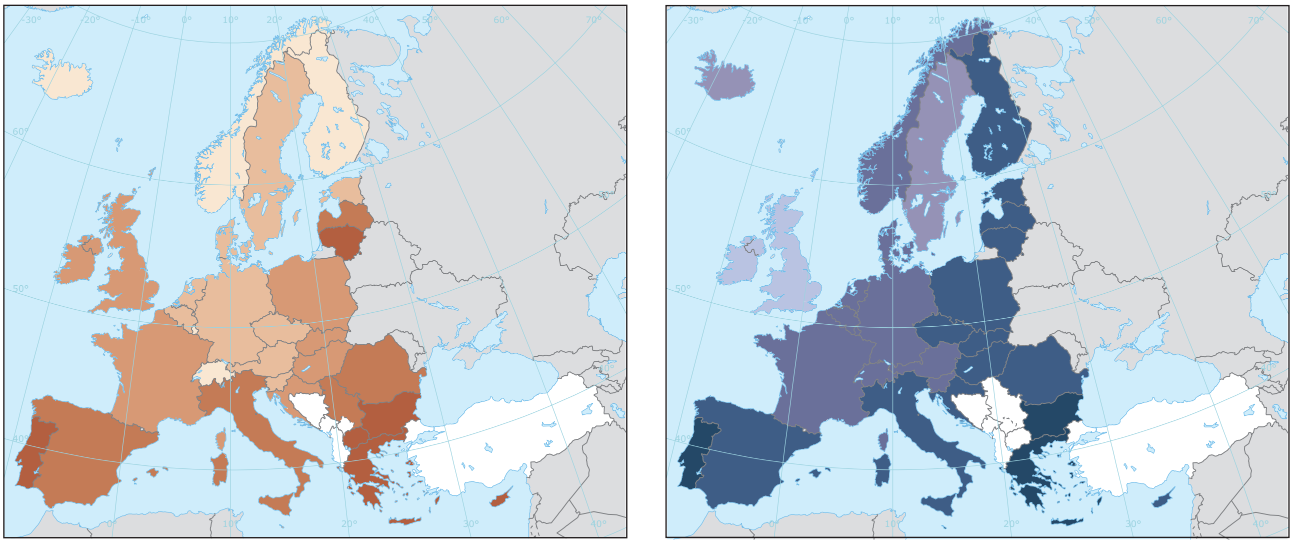
In many European countries, socially vulnerable communities live in dense, urban environments. In addition, the distribution of facilities catering for vulnerable groups, such as care homes and hospitals, have been found to be located in areas 2 °C warmer than the regional average (Macintyre et al., 2018). However, the urban centres of some cities also attract affluent individuals, exposing a wealthier cohort of the population to urban heat.

At the other end of the spectrum, living in cold housing contributes substantially to excess winter deaths (WHO Europe, 2012). With people spending nearly 90 % of their time indoors (Vardoulakis et al., 2015), those unable to afford adequate housing suffer from increased exposure to cold. The highest proportions of households unable to keep warm in winter are found in eastern and southern Europe. In 2016, nearly 10 % of the households in 33 European countries ([13]) were unable to keep their homes warm in winter (Eurostat, 2016). In terms of exposure to the cold, socio-economic status is linked to excess winter deaths. Countries with high levels of income poverty, such as Greece, Ireland and Portugal, show higher levels of winter mortality. Within Portugal, municipalities with higher socio-economic deprivation levels experienced higher excess winter mortality than places with lower levels of deprivation (Almendra et al., 2017). The homeless are vulnerable to hypothermia, even in moderately cold stress conditions (Romaszko et al., 2017) and tend to be the immediate victims of cold weather (Poljanšek et al., 2017).

Furthermore, there may be a link between socio-economic status and exposure to vector-borne

([13]) The EU-28 plus Iceland, North Macedonia, Norway, Serbia and Switzerland.

Map 4.8 **Percentages of households unable to keep their home warm during winter (2016; left) and percentages of the population living in dwellings 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

0 500 1 000 1 500 km

No data | Outside coverage

% < 5 | 5-10 | 10-20 | 20-30 | ≥ 30

Note: Countries covered in the map on the left include the EU-28, Iceland, North Macedonia, Norway, Serbia and Switzerland. Countries covered in the map on the right include the EU-28, Iceland, Norway and Switzerland.

Source: EEA (2018a).

diseases. For example, a causal link has been established between national socio-economic conditions and the upsurge in tick-borne encephalitis in countries in central and eastern Europe (Sumilo et al., 2008).

Regarding floods, there is evidence from the United Kingdom and the Netherlands of a higher level of exposure of certain social groups. A recent UK-wide analysis suggests that socially vulnerable neighbourhoods are over-represented in areas prone to flooding from all sources, but they are most significantly over-represented in areas prone to sea flooding (Sayers et al., 2017). In Greater Manchester, United Kingdom, a correlation was found between neighbourhoods' material deprivation and their exposure to surface water flooding (Kazmierczak and Cavan, 2011). Similarly, in Norfolk, United Kingdom, areas containing high proportions of residents with incomes below the national median or in receipt of a key benefit were more likely to be exposed to flooding (Garbutt et al., 2015). The same study identified higher proportions of older people, single-person households and people with poor health or disability living in areas affected by flooding (Garbutt et al., 2015). In addition, in Rotterdam, the Netherlands, areas without flood protection contain higher proportions of low-income or single-parent households, young children, migrants and the elderly than the embanked areas (Koks et al., 2015).

An overview of the results of a vulnerability assessment for a number of European cities is presented in Box 4.10.

Why are some groups less resilient to climate change?

Social factors affect an individual's ability to cope with climate change impacts, in terms of both avoiding

Box 4.10 The vulnerability of European cities to climate change

A recent indicator-based vulnerability assessment was carried out for 571 European cities. Cities more vulnerable to heatwaves were predominantly located in the central areas of the EU and in the southern regions of new Member States and the Baltic region. This was driven by the spatial coincidence of elderly populations, higher pollution levels and smaller dwelling sizes. Many cities in some of the warmest areas of Europe showed lower vulnerabilities, likely due to an awareness of the health risks of heat in these regions.

Cities vulnerable to drought, such as Brussels, Ludwigshafen am Rhein and Marseille, were found across Europe. Overall, cities with less diversified economies, growing populations and less efficient water management systems were more vulnerable.

Urban vulnerability to flooding also occurs across Europe. The British Isles and Scandinavian countries were less vulnerable than cities in Mediterranean countries, in Czechia and in the Danube river basin. Factors increasing vulnerability included low income and low employment rates, physical features, such as the extent of soil sealing, public awareness of citizens' rights and political commitment to adaptation.

For coastal flooding, cities on the Atlantic coasts, the western Mediterranean coast and the Baltic coast showed higher vulnerability than those on the coasts of the Italian Peninsula, the United Kingdom and Scandinavian countries, which were shown to have a higher capacity to adapt, as well as a higher awareness of and commitment to addressing coastal flooding.

The study results demonstrate that, for each city, the causes of vulnerability to the consequences of climate change are dependent on the specific geographical and socio-economic conditions. City-level assessments are therefore required to inform local-scale adaptation planning.

Source: Tapia et al. (2017).

stressors in the immediate term and taking action to protect themselves and their family against future risks.

Regarding resilience to flooding, those living on low incomes may not be able to afford improvements to their homes to reduce the risk from flood damage (Bichard and Kazmierczak, 2012). They are also less likely to have home contents insurance (Sayers et al., 2017) and, therefore, their relative economic losses are higher (Sayers et al., 2017). In the United Kingdom, less skilled workers and those not in work were found to have a lower level of awareness of flood risks than those in higher socio-economic groups (Fielding, 2012); in Greece, low income was also linked to a low level of flood risk awareness (Fuchs, 2017). Furthermore, in Scotland, in the aftermath of flooding, people living in lower income households suffer from an increased level of stress (Werritty et al., 2007).

Similarly, people with little connection to the area in which they live and their neighbours (e.g. those recently moved to the area, tenants) were found to be the least informed about the risk of flooding (Zsamboky et al., 2011) and the most likely to use public shelters in evacuations (Scawthorn et al., 2006). Conversely, well-established social networks support emergency responses and recovery (Preston et al., 2014). Social capital is a crucial lifeline during heatwaves or floods, particularly for those who are ill or elderly.

Individuals facing barriers to accessing information about climate-related hazards may be less ready to respond or less prepared in advance. Illiterate groups or those with a poor knowledge of the local language, such as immigrants and refugees, may therefore be less able to find information themselves, identify solutions and plan ahead (ETC/CCA, 2018).

Women are more vulnerable to the effects of climate change than men, because they have reduced access to justice, more limited mobility and a weaker voice in decision-making and policy development. This is more pronounced in lower income countries. Across Europe, socio-economic, legal and political disadvantages as well as physical and biological differences are thought to contribute to this vulnerability (ETC/CCA, 2018).

4.5 Water quality and health

Key messages:

- Pathways for human exposure to water pollution include direct exposure via drinking water extracted from groundwater or surface water or contact with contaminated bathing waters, as well as indirect exposure through the consumption of fish containing bioaccumulative pollutants, such as mercury.
- Overall, in Europe the quality of bathing water is good, with nearly 96 % of all designated sites meeting the minimum quality requirements set out in the EU's Bathing Water Directive and over 85 % achieving 'excellent' status. Overall, 1.3 % of EU bathing water sites were rated as having poor water quality, and it is in these locations that the risk of human illness is particularly increased.
- Drinking water quality across Europe also has high rates of compliance with the drinking water standards for the large supplies that serve the majority of citizens. However, there are concerns in relation to higher levels of drinking water contamination in small supplies and private wells.
- The possible presence of emerging pollutants that are not currently monitored in drinking water is also a concern. A revised Drinking Water Directive is expected to enter into force in 2020 and sets the requirement to monitor a limited number of additional pollutants.
- The situation for groundwater bodies is positive, with 74 % (by area) achieving good chemical status. This is important, as they are a significant source of drinking water across Europe.
- However, the quality status of surface water bodies in Europe is concerning, with only 40 % found to be in good ecological status and 38 % found to be in good chemical status. The chemical status of surface water is disproportionately affected by a small number of persistent, bioaccumulative and toxic chemical substance groups. This gives rise to concerns about biodiversity loss and the potential for these chemicals to enter food chains.

The EU has contributed to ensuring access to safe drinking water and sanitation for the population of its Member States through water quality standards and requirements for the treatment of urban waste water, and much effort has been put into preventing the contamination of water sources. An overview of EU policies on water is provided in Box 4.11.

Overall, progress in providing clean drinking water and recreational bathing water is good, but there are still some public health concerns in specific areas, and the quality status of some European surface water bodies is also being negatively affected by the presence of a small number of chemicals, including mercury and brominated flame retardants.

Pollutants that are found in water bodies arise from various sources, including agriculture, industry, urban waste water treatment, households and the transport sector (see Figure 4.10; EEA, 2018c). Once released into water bodies, pollutants can be transported downstream and may be discharged into coastal waters.

4.5.1 Surface water quality and health

A recent EEA report on the ecological and chemical status of European surface waters presents a concerning picture of their quality, and this has implications for the environment and human health (EEA, 2018c). In total, EU Member States reported information on the status of more than 111 000 surface water bodies, with only 40 % found to be in good ecological status and only 38 % found to be in good chemical status. However, groundwater sources presented good chemical status in 74 % of cases (these data are reported by surface area, based on data reported for 13 400 groundwater bodies).

The ability to achieve a good chemical status for European surface water bodies under the Water Framework Directive is significantly affected by a relatively small number of substance groups, namely the following (EEA, 2018d):

- Mercury and its compounds: > 45 000 surface water bodies are not achieving the required standard.

Figure 4.10 Possible sources of water pollution

Source: EEA (2018c).

Box 4.11 Water policy overview

There are a number of key directives that focus on the protection and enhancement of water quality in Europe. These are outlined briefly below.

Water Framework Directive (EU, 2000): the aim of this directive (adopted in 2000) is to establish a coherent framework for achieving the objective of 'good status' for all EU water bodies by 2015. While this ambitious objective was not met by 2015, the Water Framework Directive continues to provide the basis for achieving this objective.

Drinking Water Directive (EU, 1998): this directive, adopted in 1998, aims to ensure that water intended for human consumption is safe. The directive requires that drinking water is free of any microorganisms, parasites or substances that could potentially endanger human health. It also sets standards for the most common, potentially harmful organisms and substances that can be found in drinking water. On 1 February 2018, the Commission adopted a proposal for a revised Drinking Water Directive (EC, 2018c). The European Parliament and the Council reached provisional agreement on the recast Drinking Water Directive in December 2019, with the Directive expected to enter into force in 2020 subject to formal approval.

Urban Wastewater Treatment Directive (EU, 1991): this directive was adopted in 1991 to protect the water environment from the adverse effects of urban waste water and industrial discharges. It requires waste water collection and treatment in urban agglomerations above a certain size (based on a population equivalent loading). There are also specific requirements for discharges in sensitive areas (freshwater bodies, estuaries and coastal waters that are eutrophic or may become eutrophic if protective action is not taken). The proportion of households connected to waste water treatment plants varies across Europe. For example, in western-central Europe, the connection rate is 97 %, while in southern, south-eastern and eastern European countries, the connection rate is about 70 %. Despite improvements in recent years, around 30 million people are not connected to waste water treatment plants in Europe (EEA, 2019g).

Bathing Water Directive (EU, 2006a): the revised Bathing Water Directive was adopted in 2006. This sets stringent bathing water quality standards for the protection of public health in both coastal and inland bathing waters. The key indicators are *Escherichia coli* (*E. coli*) and intestinal enterococci, which indicate contamination from either sewage or livestock.

- PAHs: compliance rates vary for different PAHs; for example, there are more than 3 000 water bodies failing to achieve the required standard for benzo(g,h,i)perylene + indeno(1,2,3-cd)-pyrene.

- Polybrominated diphenyl ethers (PBDEs): > 23 000 water bodies are not achieving the required standard.

It was noted that, if the pollution caused by mercury and certain other priority substances ([14]) is omitted, the percentage of water bodies in good chemical status increases to 81 %. The most significant pathway for the entry of these pollutants into the water environment is related to the emission of these pollutants into the atmosphere and their subsequent deposition (particularly for mercury), and releases from urban waste water treatment plants (EEA, 2018d).

While these substances are known to be individually harmful to both humans and the environment, there is also significant concern about the impacts of mixtures of different chemicals, as discussed in Section 4.6. In addition, while not specifically addressed in this report, there are concerns about the health risks presented by microbial contamination of water bodies.

The exposure pathways for pollutants in water vary. Direct exposure routes include consumption of contaminated drinking water and exposure to poor-quality bathing waters. However, particularly in the case of chemicals in water, the most significant exposure pathway can be indirect, such as through the consumption of food. For example, some fish species can have elevated levels of mercury, as a result of mercury contamination in water bodies. This mercury can itself originate from pollutants that have been released into the air; however, direct inhalation of this mercury is not a significant exposure route. The exposure pathways and impacts of chemicals are discussed in detail in Section 4.6, while the following sections look in more detail at the potential for exposure specifically via bathing water and drinking water. Pharmaceuticals also present a particular risk to the water environment, with an overview of the key concerns presented in Box 4.12.

([14]) Ubiquitous persistent bioaccumulative and toxic substances, as defined by the Priority Substances Directive 2013: brominated diphenylethers, tributyltin, benzo(g,h,i)perylene, indeno(1,2,3-cd)-pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene and benzo(a)pyrene.

4.5.2 Bathing water quality and health

Within the EU each summer, millions of Europeans use water bodies and coastal waters for swimming, recreation and relaxation. The Bathing Water Directive applies to any element of surface water where the competent authority expects a large number of people to bathe and does not impose a permanent bathing prohibition or issue permanent advice against bathing.

To manage the water quality of bathing locations, Member States are obliged to monitor bathing water during the bathing season (which typically begins in spring and ends in early autumn, but this varies between Member States). Based on the levels of indicator bacteria present in the water, the quality may be deemed 'excellent', 'good', 'sufficient' or 'poor' (EEA, 2019h).

For the most part, non-compliance occurs because of short-term pollution events, e.g. storm water overflows (EEA, 2019h). In instances in which bathing water quality is not adequately high, mitigation measures may be required, such as the installation or upgrading of waste water treatment plants and sewage collection systems. If bathing water in a certain location is found to be of poor quality during one season, bathing must be prohibited at that location in the next season and management measures have to be taken to improve water quality. If bathing water is found to be of poor water quality for 5 consecutive years, the bathing water site has to be closed permanently.

The benefits of high-quality bathing water for health and well-being

The maintenance of good bathing water quality is important not only because of the benefits for human health, but also because it may contribute to increased use and demand for recreation activities in these locations (Breen et al., 2017).

Bathing waters are important assets for local, regional and national economies. For example, a recent survey in Scotland demonstrated that domestic visits to Scottish seaside locations generate an average of GBP 323 million in expenditure per annum (Visit Scotland, 2016). It has

Box 4.12 Pharmaceuticals in European waters

Pharmaceuticals can enter the water environment through the excretion of residual drugs that have been taken by humans or animals. Other important sources include waste water discharges from pharmaceutical manufacturing, the inappropriate management of pharmaceutical waste and the inappropriate disposal of unused drugs. While many pharmaceutical products break down into harmless metabolites, some widely used medicines are more persistent in the environment and have properties that are harmful to wildlife, such as endocrine disruption.

In general, urban waste water treatment plants are not specifically designed to remove these compounds from waste water; as a result, these materials are released into the water environment. A study by the United Nations Educational, Scientific and Cultural Organization (Unesco) and the Baltic Marine Environment Protection Commission (Helcom) examining pharmaceuticals in the Baltic Sea found that, of the 118 pharmaceutical compounds that were assessed, only nine of them were removed from waste water with an efficiency of over 95 %, and around half of the compounds were removed from waste water with an efficiency of less than 50 % (Unesco and Helcom, 2017). When pharmaceuticals are removed from waste water, they can potentially still be present in the waste water treatment plant sludges. These sludges can subsequently be applied to land, through which the pharmaceuticals can then enter the food chain and also have an impact on ecosystems. While there is still a high level of uncertainty in relation to the potential ecosystem impacts of pharmaceuticals in the water environment, but they have been associated with impacts such as spawning, reproductive, developmental and behavioural effects (CHEM Trust, 2014).

One of the key issues associated with pharmaceuticals in the environment is antimicrobial resistance (AMR). Bacteria naturally develop resistance to antibiotics; however, the widespread use of antibiotics in humans and animals can significantly accelerate the emergence and spread of antibiotic-resistant bacteria. These bacteria can then spread leading to increased levels of infection among the human and animal populations. In the broader environment, the role of AMR genes in the spread of antibiotic-resistant bacteria is currently unclear. Infections caused by multidrug-resistant bacteria are estimated to cause 25 000 deaths in the EU every year, while AMR also places a burden on healthcare systems and society, with an annual cost due to healthcare expenditures and productivity losses estimated at approximately EUR 1.5 billion in the EU (European Medicines Agency, 2019). The European Commission launched the 'One Health' action plan in 2017 to specifically address the issues of AMR, which includes measures such as reducing the use of antimicrobials in both humans and animals (EC, 2017b). The plan acknowledges the environment as a contributor to the development and spread of AMR in humans and animals and notes that strong evidence is required to better inform decision-making. The European Commission has also recently launched the 'European Union strategic approach to pharmaceuticals in the environment' (EC, 2019h) to tackle these issues and promote 'green design' within the pharmaceutical sector. The Farm to Fork Strategy recognises that antimicrobial resistance is linked to the use of antimicrobials in animal husbandry and human healthcare and commits to halving sales of antimicrobials for farmed animals and aquaculture by 2030 (EC, 2020b).

been shown that, with improvements to bathing water quality, there are increases in welfare per trip (Hanley et al., 2003). In addition, in Ireland it was found that higher levels of recreational demand (trips of longer duration) occur at bathing sites with better water quality (Breen et al., 2017). The inverse of this benefit should, however, also be considered, as environmental impacts may occur from the use of bathing waters. For example, a recent study demonstrated the effects that water-based recreational activities may have on the integrity of freshwater ecosystems (Venohr et al., 2018). Potential adverse impacts, such as the ecotoxicological effects of sunscreen, should be considered when establishing new bathing waters.

Aside from reducing the frequency of use of an individual bathing site (Hanley et al., 2003), poor water quality is undesirable because of the negative impacts it may have on health. Pollution may arise from faecal contamination due to farm waste, cesspits, septic tanks and poorly protected plumbing. Faecal contamination can lead to intestinal illness and more severe illnesses, such as acute febrile respiratory illness (EEA, 2016d; Kay et al., 1994).

Another possible effect is eutrophication in bathing waters. Nutrient enrichment may cause the excessive growth of plankton algae, which increases the concentration of chlorophylla. This in turn may result in an increase in the frequency and duration of phytoplankton blooms and in hazards to human health in the case of toxic cyanobacteria (bluegreen algae) (EEA, 2012).

Bathing water quality across the Europe

Across Europe, there are 22 295 bathing water sites monitored for their water quality. In 2019, 95 % of all sites met the minimum quality requirements set out in the EU's Bathing Water Directive, with 84.6 % achieving 'excellent' status. Only 1.3 % of EU bathing water sites were rated as having poor water quality, and it is in these locations that the risk of human illness is highest. In general, coastal bathing water is of better quality than that of inland sites. In 2019, 87.4 %, of coastal bathing sites were classified as of excellent quality compared to 79.1 % of inland sites in the EU (EEA, 2020b).

There are differences in bathing water quality across Europe, as presented in Figure 4.11. All reported bathing water sites in Greece, Latvia, Lithuania, Luxembourg, Romania and Slovenia achieved at least sufficient quality in 2019. In five countries, 95 % or more of bathing waters were assessed as being of excellent quality: Cyprus (99.1 % of all sites), Austria (98.5 % of all sites), Malta (97.7 % of all sites), Greece (95.7 % of all sites) and Croatia (95.6 % of all sites) (EEA, 2020b).

In six European countries, 3 % or more of bathing waters were of poor quality: Albania (seven bathing waters or 5.9 %), Estonia (three bathing waters or 5.6 %), Hungary (10 bathing waters or 3.9 %), Ireland (five bathing waters or 3.4 %), the Netherlands (24 bathing waters or 3.3 %) and Slovakia (one bathing water or 3.1 %) (EEA, 2020b).

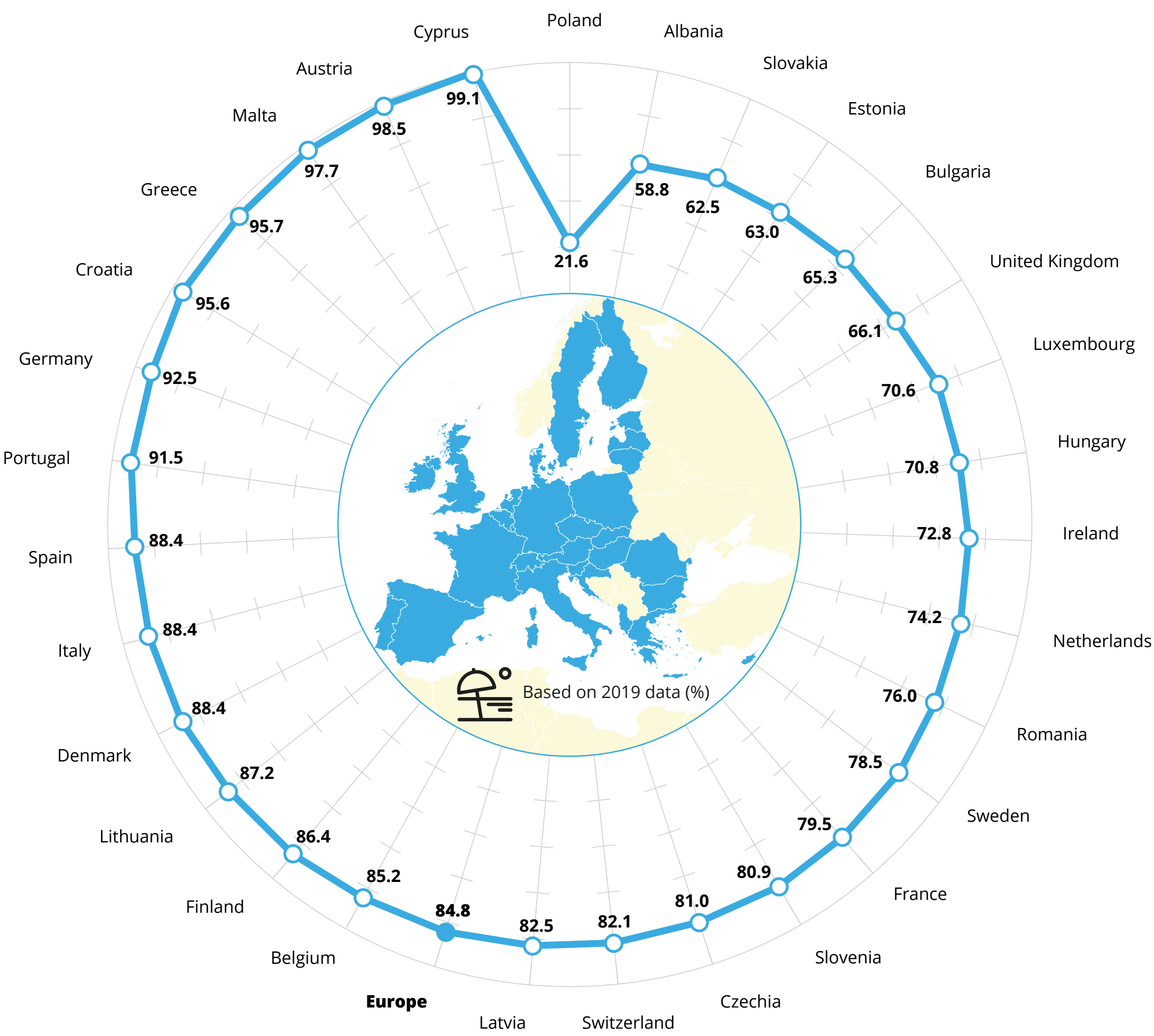
4.5.3 Drinking water quality and health

Drinking water across the EU is regulated under the Drinking Water Directive. The directive applies to drinking water from tankers, bottles or containers, the food-processing industry and all distribution systems serving more than 50 people or supplying more than 10 m^3 per day (or less if the water is supplied as part of an economic activity). There is a distinction between large and small supplies of water; Member States are obliged to monitor large supplies but not small supplies. Drinking water comes from groundwater (50 %) and surface water (36 %) across the EU (EC, 2016b).

Under the directive, Member States must monitor the quality of the drinking water supplied to consumers across a total of 47 parameters. These include microbiological, chemical and indicator parameters. Similar to the Bathing Water Directive, the biological parameters are based on *Escherichia coli* (*E. coli*) and intestinal enterococci, which should in effect be entirely absent from drinking water to guarantee its quality and safety. The chemicals monitored represent some of the most concerning chemicals that are relevant to human health, totalling 26 different parameters. These include pesticides, mercury, nitrate, cyanide, fluoride, acrylamide and arsenic. The indicator parameters serve to indicate a change in the water source or the treatment or distribution of the water, and include parameters such as odour, colour, chloride, sulphate and turbidity.

In February 2018, the Commission published a proposal for a recast of the Drinking Water Directive. While an evaluation of the existing directive found it was broadly fit for purpose, a number of updates and additions were proposed for the recast directive. These included updating the standards (including adding new substances), providing for a risk-based approach to monitoring to allow resources to be applied to the highest risk areas, improving public access to information on drinking water, taking measures to

Figure 4.11 Proportion of bathing water sites with excellent water quality in 2019



Source: EEA (2020b).

harmonise the standards for materials in contact with drinking water and taking measures to improve overall public access to drinking water (EC, 2018c).

Drinking water quality across the EU

The provision of safe and clean drinking water is generally seen as a fundamental right for citizens and hence governments tend to prioritise a sufficient supply of good-quality drinking water. In general, compliance levels are high for larger water supplies, which serve the vast majority of EU citizens; between 2011 and 2013, there was over 99 % compliance for microbiological and chemical parameters and more than 98.5 % compliance for indicator parameters (EC, 2016b), as illustrated in Figure 4.12. Overall, the highest number of exceedances related to *E. coli* contamination. Of all the chemical parameters, arsenic was shown to exhibit the lowest compliance rate (98.8 %). This slightly lower compliance rate was due to the geological background concentration that can be found in some countries.

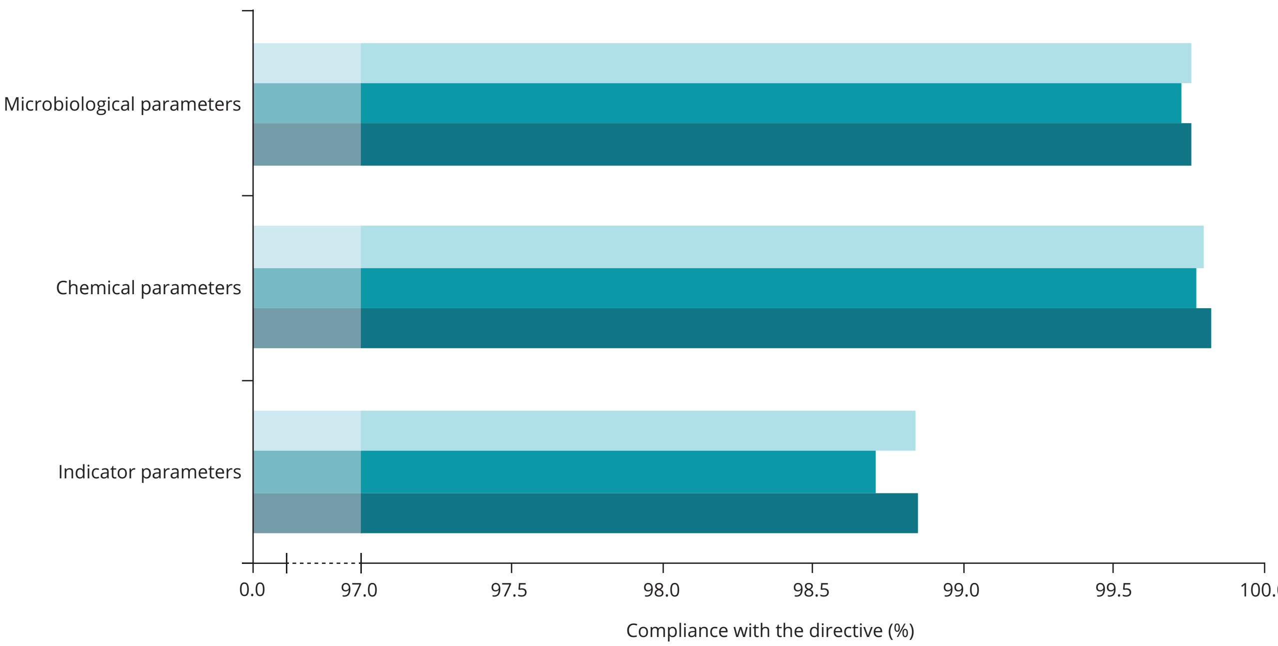
Within the indicator parameter group, the greatest numbers of exceedances were for total organic carbon and iron (EC, 2016b). Overall, no major differences between Member States were observed. These very high compliance rates highlight the success of the efforts that have been made at a European level to ensure that drinking water is fit for purpose.

With respect to pesticides, there are specific limits to the quantities present in drinking water. In this instance, the specific pesticides that are tested depend on individual Member State use of pesticides (only pesticides likely to be present in a given supply need to be tested). For reporting purposes, a list of 13 pesticides was agreed between the European Commission and Member States. Based on data from 2011 to 2013 (EC, 2016b), monitoring rates for pesticides were low (27.4 %), which does not allow a comprehensive assessment of pesticide contamination in drinking water. However, a risk assessment carried out in France found that the contribution of tap water to dietary exposure to pesticides is generally low (ANSES, 2013b).

Apart from the larger public supplies regulated under the Drinking Water Directive, the directive also includes requirements for 'small supplies', which are defined as those that supply less than 1 000 m^3 per day or less than 5 000 people. A 2009 European Commission review of monitoring data for small supplies found that monitoring data were generally limited and if they were available they were not complete. Overall, the compliance rate for small supplies was estimated at around 60 %, with respect to microbiological parameters (EC, 2016c). This is obviously significantly lower than the compliance rates for larger supplies. This is particularly concerning, as in 2010 it was estimated that there were 85 000 small supplies in the EU providing drinking water to approximately 65 million citizens (EC, 2016c).

There is less information readily available on private wells and the regulatory regime varies from country to country. For example, in Germany only 0.7 % of the population is served by private wells; however, these wells are still required to meet the minimum requirements stipulated in the German Drinking Water Ordinance for small supplies (UBA, 2018). Conversely, in Ireland, approximately 11 % of the population is supplied by private wells, which are effectively exempt from regulation. The onus is therefore on the owner of the well to carry out testing and satisfy themselves that the water is fit for consumption (DHPLG, 2019). It is estimated that 30 % of the 170 000 private wells in Ireland are contaminated with *E.coli* arising from human or animal waste (EPA, 2017). The Irish authorities have also reported a growing number of cases of VTEC (verocytotoxigenic *E. coli*) — a pathogenic form of *E. coli* — and, while drinking water is not the only potential source of exposure, an analysis of cases shows that patients suffering from VTEC are up to four

Figure 4.12 Percentage compliance for the parameter groups — microbiological parameters, chemical parameters and indicator parameters — for the reporting period 2011-2013 in the EU



Source: EEA (2016d).

Box 4.13 Responding to per- and polyfluorinated alkyl substance contamination of drinking water in the Veneto region of Italy

In 2013, drinking water was found to be contaminated by per- and polyfluorinated alkyl substances (PFASs) in an area of the Veneto region, Italy, by the Regional Agency for Environmental Protection and Prevention (ARPAV). Emissions of fluorinated chemicals from a local manufacturing company had contaminated groundwater, surface water and drinking water. PFASs have negative health impacts, including pregnancy complications, thyroid disease, high cholesterol and cancer (EEA, 2019i).

In response, the Italian National Health Institute defined maximum levels of PFASs in drinking water, which were then extended to cover water for livestock and agriculture. Carbon filters were installed to remove PFASs from drinking water in the area, and PFAS concentrations were monitored in drinking water, groundwater, surface water, soil, air and food, and in the exposed population. A retrospective health impact assessment approach was used to identify mitigation and remediation measures, and inform risk communication and future monitoring and epidemiological studies (WHO Europe, 2017c).

During a follow-up, a study assessed mortality rates for adverse health outcomes possibly associated with PFAS exposure and found higher mortality rates in contaminated areas where these levels were exceeded than in uncontaminated areas. Higher risks were detected for general mortality, kidney and breast cancers, diabetes, cerebrovascular diseases, myocardial infarction, Alzheimer's and Parkinson's diseases (Mastrantonio et al., 2017).

times more likely to have consumed untreated water from household wells (EPA, 2017). Ireland also has the highest number of reported VTEC cases in Europe, with 757 reported in 2015 (EPA, 2017). In Austria, about 10 % of the population use private wells, and, as in Ireland, there is no formal regulation of these wells (BMNT, 2018). Overall, data on the usage and quality of water from private wells in Europe are limited, but available evidence suggests that they may be a cause for concern.

Emerging contaminants

The Drinking Water Directive requires the assessment of water quality based on a range of pollutants of concern. However, there are other 'unregulated' chemicals found in drinking water that are also of concern. For example, the presence of pollutants such as pharmaceuticals, brominated flame retardants, nanomaterials, chemicals present in sunscreens or dibutyl phthalates. The statement of the Scientific Committee on Health, Environmental and Emerging Risks (Scheer) on emerging issues (Scheer, 2018) highlighted the potential risk posed by polar organic compounds, referred to as persistent mobile organic chemicals. These substances are very difficult to remove during water treatment activities and hence there is the potential that their environmental concentrations will increase over time as they circulate and become enriched in the water cycle, potentially entering the drinking water supply (Scheer, 2018). A review of emerging contaminants by Villaneuva et al. (2014) indicates that, while the risks posed by these chemicals individually may be low, there are concerns about the risk of exposures to mixtures, while there is limited knowledge on the ability of drinking water treatment plants to remove these pollutants. The study concluded that there is a particular knowledge gap and a need to evaluate human exposure and the risks posed by a wide range of emerging contaminants. Wee and Aris (2017) also noted that the exposure of humans to endocrine-disrupting chemicals through drinking water is under-researched but may be an important route of exposure.

Box 4.13 presents a case study on recent drinking water contamination from an industrial source in the Veneto region of Italy.

In addition to emerging pollutants, trends such as increasing levels of urbanisation, the intensification of food production activities and the effects of climate change are also likely to present significant challenges in terms of protecting drinking water supplies.

Acknowledging the risk from emerging contaminants, a recent revision of the Drinking Water Directive includes limits for some additional pollutants, including limits for some perfluorinated compounds (EC, 2018c).

Another emerging concern is the contamination of drinking water with plastic fibres (Tyree and Morrison, 2017). It was found that 74 % of European samples

Box 4.14 Microplastics

Plastics are an intrinsic part of modern life. In the EU, the annual demand for plastics is estimated at around 49 million tonnes, while nearly 26 million tonnes of plastic waste is generated annually, with less than 30 % of this being sent for recycling). The risks posed by plastics and the need to address concerns around the way plastics are produced, used and discarded has been recognised through the adoption of the first 'European strategy for plastics in a circular economy' (EC, 2018d).

Within the strategy, the issue of microplastics (plastic particles less than 5 mm in size) is also addressed, with estimates of between 75 000 and 300 000 tonnes of microplastics being released into the environment in Europe every year. A study of the Danube river by the Austrian Environment Agency (UBA) identified the loading of microplastics in the river at between 6 and 66 kg per day, with the overall annual loading estimated at up to 17 tonnes. Only 10 % of the plastics were identified as being definitely from industrial activities, with the remainder being from other diffuse sources. These sources include run-off from roads, litter, construction activities and cosmetics (ICPDR, 2016).

Apart from the potential risks posed by the presence of plastics in drinking water, their small size means they can easily be ingested by marine animals and can thus find their way into the human food chain as well as have an impact on the health of the animals themselves. One particular area of concern is the intentional use of microplastics in personal care products, such as exfoliates, with a number of EU Member States already placing restrictions on their use. The European Chemicals Agency has investigated the risk posed by the intentional use of microplastics in products and has recently proposed an EU-wide restriction, which, if enacted, would prevent the release of up to 400 000 tonnes of microplastics into the environment over the next 20 years (ECHA, 2019).

To date, the assessment of the impact of plastics has focused on ecosystem impacts rather than on human impacts, with limited evidence available in relation to the impacts on humans (Toussaint et al., 2019) and on the levels of microplastics present in drinking water (WHO, 2019b). Nonetheless, an initial review by the World Health Organization concludes that there is no reliable information available to suggest that microplastics in drinking water are currently a concern (WHO, 2019b). A report from the Scientific Advice Mechanism (SAM) Group of Chief Scientific Advisors summarises the environmental and health risks of microplastics by stating that, although the evidence currently available suggests that microplastic pollution at present does not pose a widespread risk to humans or the environment, there are significant grounds for concern and for precautionary measures to be taken. High-quality risk assessment approaches are essential to prioritise such measures and to determine when and where to apply them (Group of Chief Scientific Advisors, 2019).

tested positive for plastic. A separate study in Ireland highlighted the lack of knowledge regarding pathways into freshwater, exposure rates and health impacts (Mahon et al., 2014). Box 4.14 provides an overview of the issues related to microplastics.

Health impacts of poor-quality drinking water

To an even greater extent than bathing water, the presence of microbiological parameters in drinking water has the potential to cause health implications, mostly as a result of intestinal illness. It is difficult to approximate the true disease burden across Europe, but it is likely to be underestimated (WHO Europe, 2016b). Importantly, with climate change increasing the number of heavy precipitation events, droughts and flooding events across Europe, there is potential for water-borne outbreaks of diseases to increase (Brown and Murray, 2013). Recently, there have been outbreaks of *Cryptosporidium* across much of Europe, which is a significant cause of diarrhoeal disease (Caccio and Chalmers, 2016). These are often significant public health events; for example, during the period 2010-2011 in Sweden, there were two outbreaks that affected an estimated 47 000 people (Rehn et al., 2015).

Localised lead contamination of drinking water may also still be a problem in some European countries. A study in 2009 estimated that 25 % of domestic dwellings in the EU had lead pipes as part of their water supply system, potentially having an impact on 120 million people (Hayes and Skubala, 2009). Nonetheless, European monitoring data on lead in drinking water do not indicate a significant compliance issue.

The presence of chemicals in drinking water also has the potential to affect human health; the health impact of chemicals is addressed in more detail in Section 4.6.

Disparities in the availability of clean drinking water

Despite the fact that monitoring is good across the EU and that compliance regarding pollutants in drinking water is high, there are areas of Europe in which access to clean drinking water is not comprehensive. In a recent WHO Europe report, an assessment of small-scale rural water supplies in Serbia found that only 37 % of piped systems (serving up to 10 000 people) and 17 % of individual supplies (serving less than five households or 20 inhabitants) complied with the national standards for microbiological and physico-chemical parameters (WHO Europe, 2017d). This is despite the fact that, in 2016, Serbian urban water supply systems had compliance rates of over 90 % for physico-chemical and microbiological parameters.

There are disparities in access to safe drinking water along ethnic lines in Europe. The Roma are the largest ethnic minority in the EU, and in 2016 the European Union Agency for Fundamental Rights found that across nine European countries ([15]), an average of 30 % of Roma live in households with no tap water. Considerable variation was seen across countries, with less than one in ten Roma living in households without a tap in Spain (2 %), Czechia (2 %) and Greece (9 %), and higher proportions seen in Portugal (14 %), Bulgaria (23 %), Slovakia (27 %), Croatia (34 %), Hungary (33 %) and Romania (68 %) (European Union Agency for Fundamental Rights, 2016). A 2017 study investigated access to safe and affordable drinking water at 93 Roma sites in seven countries, including Albania, France, Hungary, North Macedonia, Moldova, Montenegro, and Slovakia, and found that at 81 % of the sites, Romani households were not connected to the water mains (European Roma Rights Centre, 2017).

Migrants and asylum seekers in Europe also suffer limited access to drinking water, with specific concerns at Europe's formal and informal refugee camps. For example, prior to the demolition in 2016 of Europe's largest formal refugee camp on the outskirts of Calais, the 'Jungle' or Camp de la Lande, a population of 3 000 had access to five piped water taps. Residents used containers previously used to contain hazardous chemicals to transport and store water, with containers found to be contaminated with harmful bacteria (Dhesi et al., 2018). Following the dismantling of the Jungle, people continue to live in informal camps, with efforts now underway to move people into accommodation centres. There is currently an urgent need to improve access to water at reception centres on the Aegean Islands in Greece (United Nations High Commission for Refugees, 2020).

The section above on drinking water quality in the EU also highlights the fact that people served by small supplies and private wells are likely to be at greater risk than those served by larger supplies. The recast of the Drinking Water Directive seeks to address this disparity in the availability of clean drinking water. The European Citizens' Initiative on access to drinking water, 'Right2Water', is described in Box 4.15.

The United Nations Economic Commission for Europe (UNECE) Protocol on Water and Health also focuses on addressing inequities in access to safe drinking water (UNECE, 1999), and in addition supports work towards the achievement of Sustainable Development Goal 6: 'ensure availability and sustainable management of water and sanitation for all'. A number of EU Member States are signatories to this legally binding protocol.

Box 4.15 Citizens' initiative on access to drinking water

The European Citizens' Initiative allows citizens to call on the European Commission to propose legislation on matters of EU competence when there are greater than 1 million signatories.

'Right2Water' was an initiative that was submitted to the Commission by its organisers on 20 December 2013 and that received support from over 1.6 million citizens (Right2Water, 2019). The Right2Water initiative was launched to ensure that water remains a public service and a public good, with proposals including using 'Human Right to Water and Sanitation' in all communications on water and/or sanitation, to guarantee water and sanitation services to all EU citizens and to prevent its liberalisation.

The Commission responded positively to this initiative, which included launching an EU-wide public consultation on the Drinking Water Directive. Furthermore, as part of its resolution of 8 September 2015 on the follow-up, the European Parliament recognised that water is not a commodity but a public good and one that it is vital to human life.

The Commission proposal for a revised Drinking Water Directive (EC, 2018c), expected to enter into force in 2020 subject to formal approval, came in direct follow up to the Right2Water European Citizens' Initiative.

([15]) Bulgaria, Croatia, Czechia, Greece, Hungary, Portugal, Slovakia, Spain and Romania.

4.6 Chemicals and health

Key messages:

- Exposure to hazardous chemicals contributes to the burden of disease in Europe, with certain chemicals associated with chronic diseases, neurological disorders and developmental effects in unborn children.
- At global level, 2.7 % of the burden of disease and 1.7 % of total deaths are attributed to chemicals.
- Human exposure to well-known hazardous substances has decreased in Europe as a result of policy measures. At the same time, the volume and diversity of chemicals flowing through production and consumption systems continues to increase.
- The total burden of chemicals on human health is not known. There are gaps in knowledge regarding hazards and current exposure levels of the European population to chemicals are also unknown. The impacts of exposure to endocrine disruptors and chemical mixtures are not well understood.
- Children and pregnant women are more sensitive to the adverse effects of chemicals, with exposure to certain hazardous chemicals associated with developmental effects.
- Early evidence suggests that social status is a driver of human exposure to chemicals, with exposure patterns influenced by behaviours such as consumer choices, dietary preferences and smoking.

Chemical safety is a matter of public concern, with one in four EU citizens 'very concerned' about exposure to chemicals in their daily lives (EC, 2017c). Understanding the risks posed by chemicals requires evidence on the two dimensions of chemical risk — hazard and exposure — as explained in Box 4.16.

The volume and diversity of chemicals produced and consumed grew substantially over the past century and continues to increase (CEFIC, 2018). Of the 314 million tonnes of chemicals consumed in the EU in 2018, 71 % were classified as hazardous to health (Eurostat, 2020e). In terms of diversity, 22 920 unique substances had been registered under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulation (EU, 2006b) by July 2020.

This figure does not capture pharmaceuticals and pesticides (although raw material chemical inputs will be captured) or chemicals on the market at low tonnage (i.e. < 1 tonne). Once emitted into the environment, chemicals degrade into an unknown number of metabolites.

People are exposed to a complex mixture of chemicals in their daily lives by breathing in polluted air and dust, consuming contaminated food and drink and coming into contact with consumer goods (see Figure 4.13). A foetus can be exposed in the womb to chemicals in the body of the mother that cross the placental barriers, while babies can be exposed via their mother's breast milk. The chemical body burden results from combined daily chemical exposures as well as persistent chemicals that entered the body during past exposures and accumulate in tissues. Substances include synthetic chemicals, such as industrial chemicals, pharmaceuticals, pesticides and biocides, chemical pollutants unintentionally emitted from industrial processes and combustion, and chemicals that occur naturally in the environment.

Current efforts to establish a circular economy to reduce the impacts of production and consumption may generate new risks in terms of chemical exposure via consumer products. The recycling of products that contain hazardous chemicals can contaminate material flows — an example being recycled plastics containing brominated flame retardants. Some of the potential risks associated with a circular economy are more likely to have an impact on vulnerable groups, for example workers in the waste management sector (WHO Europe, 2018). Decisions on how to move forward require reflection on the optimal balance between removing hazardous materials from circulation and maximising resource efficiency for each material flow. The consideration of unintended adverse effects is an important part of the development of relevant policies.

At the same time, there are opportunities to pursue circularity in chemical flows, for example through closed-loop mechanical recycling of plastics (Stenmarck et al., 2017). Another opportunity is the extraction of hazardous chemicals from chemical waste streams and their recycling.

Box 4.16 The dimensions of chemical risk — hazard and exposure

The **risk** of harm from any chemical results from a combination of the hazard associated with the chemical and the level of exposure to the chemical.

Hazard refers to the properties of a chemical that make it toxic, meaning it can cause harm to human health.

Exposure describes the amount of a chemical that an individual comes into contact with, as well as the frequency of contact. The duration of exposure is also a significant factor in assessing the risk posed by a chemical.

Figure 4.13 Sources of chemicals and exposure routes for humans

Source: EEA (2019a).

Box 4.17 EU chemical policies

The EU has a large body of policies regulating chemicals. The Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulation (EU, 2006b) is the key horizontal legislation that aims to protect human health and the environment. The REACH Regulation obliges companies to provide information on the properties and hazards of the chemicals that they manufacture and market in the EU in registration dossiers, as well as manage the associated risks. The regulation also calls for the progressive substitution of the most hazardous chemicals, when economically and technically suitable alternatives have been identified. This is done by enforcing restrictions on their uses or by authorising the chemical uses for defined purposes.

The Classification, Labelling and Packaging (CLP) Regulation (EU, 2008b) protects human health and the environment by putting in place rules for the classification, labelling and packaging of chemicals and ensuring that information about hazards is communicated down the supply chain.

Regarding chemical products, the EU has a comprehensive body of legislation to regulate chemicals in detergents, biocides, plant protection products and pharmaceuticals. Policies limit the use and presence of hazardous chemicals in consumer products, to ensure consumer safety and protect the environment from diffuse emissions, including personal care products, cosmetics, textiles, electronic equipment and food contact materials. Limits are also in place for chemicals in food and drinking water.

European policies for environmental quality set maximum thresholds for the presence of certain chemicals in air and water bodies. Legislation addresses point source emissions from industrial installations and from urban waste water treatment plants. Emissions of chemicals that are hazardous and of global concern because of the transboundary nature of their impacts, such as persistent organic pollutants and mercury, are also regulated.

The European Green Deal foresees actions to protect human health from chemicals. Both the Farm to Fork Strategy (EC, 2020b) and the Biodiversity Strategy (EC, 2020c) aim to halve the use and risk of pesticides by 2050, and to halve the use of more hazardous pesticides by 2030. The Circular Economy Action Plan recognises the potential risks of contaminated secondary material flows, and foresees measures to improve the tracking and management of hazardous chemicals in material flows, and to support the development of methods to remove contaminants from waste (EC, 2020e). In late 2020, the Commission will present a chemicals strategy for sustainability, to better protect health and the environment and to encourage innovation for safe and sustainable alternatives. An alignment of policies with the latest scientific evidence on endocrine disruptors, hazardous chemicals in products, chemical mixtures and very persistent chemicals is foreseen (EC, 2019a).

An overview of EU chemical policies is provided in Box 4.17.

4.6.1 Health impacts of chemicals

The human health impacts of chemicals are considerable. The World Health Organization estimates that 2.7 % of the total disease burden and 1.7 % of total deaths were attributed to chemicals globally in 2016 (WHO, 2018c). The scope of this estimation was confined to a small number of chemicals for which causality is well described. The health impacts of chemicals are thought to be underestimated because of the challenges of understanding exposure to chemicals over a lifetime and associating this exposure with disease outcomes to establish causality. Exposure to hazardous chemicals is known to be associated with a wide range of serious health impacts, including chronic diseases, neurological disorders and developmental effects in unborn children (Prüss-Ustün et al., 2011).

In terms of translating health costs into economic terms, an assessment of the economic costs of adverse effects on human brain development resulting from exposure to just four types of neurotoxicants ([16]) estimated costs greater than 2.5 % of global GDP (Grandjean and Bellanger, 2017). Most recently, the annual health-related costs in the EU associated with the group of PFASs were estimated at EUR 52-84 billion for all countries in the European Economic Area (Goldenman et al., 2019).

The EU has the most comprehensive and advanced chemicals legislation in the world, spearheaded by the REACH Regulation. Under REACH, the understanding of which substances are produced and used in the EU and the associated risks has improved dramatically. Nevertheless, the quality of information on chemical risks reported by industry is often poor, with 32 % of dossiers for the highest tonnage rate (1 000 tonne per year and above) found to be non-compliant with information requirements (BFR, 2018). In addition, information on long-term impacts is lacking, and an estimate of the overall impact of chemicals on human health is not possible. Efforts are under way to prioritise substances of potential concern and evaluate the potential risks, with the aim of identifying those substances that should be subject to controls (ECHA, 2018a).

([16]) The four types of neurotoxicant included in the study are lead, methylmercury, PBDEs and organophosphate pesticides.

Current concerns related to unknowns include the health effects of endocrine-disrupting chemicals — often at low doses (see Box 4.18) — the effects of mixtures of chemicals (see Box 4.19) and the health impacts of exposure to pesticides (see Box 4.20). In addition, as new substances come onto the market, evidence regarding hazards and exposure for assessing risk is generally limited or lacking. Such emerging substances may initially be used at low tonnage bands, for which information requirements for registration under REACH are low. In several cases, chemicals known to be hazardous have been substituted by new alternative substances with a similar chemical structure but for which toxicity data are not available. Several of these alternative substances have later been found to exhibit similar toxicities, an outcome known as 'regrettable substitution'. The European Chemicals Agency (ECHA) has a substitution strategy in place to support informed and meaningful substitution of chemicals of concern in the EU and boost the availability and adoption of safer alternative substances and technologies (ECHA, 2018b).

4.6.2 Sensitivity of vulnerable groups

Certain demographic groups are more vulnerable to the toxic effects of chemicals, including children and pregnant women.

Exposure to various chemicals, including lead, mercury, flame retardants, plasticisers and other endocrine-disrupting chemicals, in early childhood has been associated with a range of neurodevelopmental effects. Exposure to certain solvents or pesticides in early life may induce Parkinson's disease in later life (WHO, 2016e). Testicular cancer in men and breast cancer in women are suspected to be linked to early-life or prenatal exposures (Grandjean et al., 2008). Young children are more exposed to chemicals because of their proximity to house dust when crawling, their increased breathing rate, their hand-to-mouth behaviour and their higher consumption of water and food relative to their size, in particular fruit and vegetables.

Box 4.18 Health impacts of exposure to endocrine disruptors

Endocrine disruptors are chemicals that may interfere with the normal functioning of the body's hormone system. This can result in impacts on development, fertility and the neurological and immune systems. Approximately 800 chemicals are known or suspected to be endocrine disruptors, with many present in everyday products, such as metal food cans, plastic consumer products, pesticides, food and cosmetics.

Humans are the most sensitive to the health effects of endocrine disruption when *in utero*, early childhood and puberty (WHO and UNEP, 2013). There is evidence that exposure to endocrine-disrupting chemicals plays a causal role in a range of health outcomes, including a decrease in IQ (Intelligence Quotient) and associated intellectual disability, autism, attention deficit hyperactivity disorder, childhood obesity, adult obesity, adult diabetes, cryptorchidism, male infertility and mortality associated with reduced testosterone. The disease and dysfunction caused by exposure to endocrine-disrupting chemicals have been estimated to cause EUR 157 billion in annual healthcare costs and lost earnings within the EU (Trasande et al., 2015).

In 2018, the Commission published a communication entitled 'Towards a comprehensive European Union framework on endocrine disruptors', setting out a strategy to address the health effects of endocrine disruptors, as well as efforts to build knowledge (EC, 2018e).

Box 4.19 Health impacts of exposure to mixtures of chemicals

While the current approach to chemical risk assessment is based on single substances, the reality is that people are exposed to a mixture of chemicals in their daily lives. Chemicals that have an impact on the human body in a similar way can act jointly to produce a combination of effects that are larger than the effects of a single chemical (EC, 2011a). Combined exposure to a mixture of chemicals can lead to health effects, even if single substances in the mixture do not exceed safe levels.

This presents a challenge, since chemicals are predominately regulated by establishing safe thresholds for single substances (JRC, 2017). Recognising this, the Commission implemented a programme of work on chemical mixtures (EC, 2012a). Efforts are under way to develop methods for risk assessments for mixtures of chemicals (Bopp, et al., 2018), and there have been early discussions of proposals to lower safety limits for single chemicals through a mixture assessment factor to account for combined effects (Kortenkamp and Faust, 2018). The European Food Safety Authority (EFSA) has published guidance on methodologies for combined chemical risk assessment (EFSA, 2019a).

Regarding pregnant women, exposure to certain pesticides and phthalates has been linked to reductions in placental weight and premature birth. Foetuses are extremely vulnerable because of the sensitivity of the chemical signalling that steers early human development and the potential for disruption when exposed to chemicals. Congenital malformations have been linked to chemical exposure, including congenital heart disease linked to exposure to pesticides and organic solvents, cryptorchidism and hypospadias linked to endocrine-disrupting chemicals and urinary malformations linked to pesticides (WHO, 2016e).

The elderly may be more vulnerable, as the physiological processes that metabolise and eliminate chemicals become less effective as a result of ageing. However, there is a lack of knowledge regarding the effects of chemical exposure in ageing populations (Risher et al., 2010).

4.6.3 Social status and exposure to hazardous chemicals in Europe

Human biomonitoring provides a tool for understanding the chemical burden on the body and exploring trends in exposure over time and across social and demographic groups (see Box 4.21). There is evidence from human biomonitoring studies that social status is a driver of human exposure to chemicals, with exposure patterns influenced by behaviours such as product use, dietary preferences and smoking, as well as housing quality. However, the patterns of inequalities in exposure differ depending on the chemical. The available evidence from individual countries is considered below, complemented by the results of an analysis of the influence of education levels on exposure in 17 European countries.

Evidence of the influence of social status on chemical exposure from various countries

Studies from several European countries have found dimensions of social deprivation to be associated with higher levels of exposure to certain chemicals. A German study found that household chemicals that can have an impact on health, such as certain disinfectants, indoor sprays and detergents, were more frequently used by households of low social status (Seiwert et al., 2008). Exposure to bisphenol A (BPA) was found to be associated with low socio-economic status in Spain (Casas et al., 2011) and Belgium (Geens et al., 2014). Possible drivers include exposure to tobacco smoke, as cigarette filters contain a small amount of BPA, and the consumption of canned food, as BPA is present in the epoxy resin lining of cans.

Box 4.20 Human exposure to pesticides

For the general population, exposure to pesticides occurs through the consumption of food containing pesticide residues. A high intake of fruit and vegetables is positively correlated with a higher body burden of pesticides, while frequent consumption of organic products is associated with a lower pesticide burden (Berman et al., 2016). Children have a higher food intake per kilogram of body weight, leading to higher exposure levels. Domestic pesticide use and living in the vicinity of crops treated with pesticides can also lead to exposure (Dereumeaux et al., 2018). As a result of the neurotoxic and endocrine-disrupting properties of some pesticides, pregnant women and children are considered the most vulnerable population groups.

The EU regulates pesticides under the Regulation on Plant Protection Products (EU, 2009a) and sets safe limits for pesticide residues in food and feed (EU, 2005). The latest monitoring information from the European Food Safety Authority (EFSA) found 96 % of food samples collected across the EU in 2017 to be within legal limits, with just over 54 % free of quantifiable residues (EFSA, 2019b). EFSA has also developed methodologies to carry out assessments of the risks posed to humans by residues of multiple pesticides in food. The first step was the establishment of cumulative assessment groups of pesticides on the basis of their toxicological profile (EFSA, 2019c). A second step involved piloting the approach through two assessments of the cumulative risks of pesticides for the nervous systems and the thyroid.

Nevertheless, there is considerable public concern regarding the health impacts of pesticides in the EU, as evidenced by the European Citizens' Initiative to 'ban glyphosate and protect people and the environment from toxic chemicals' (EU, 2017). Efforts are currently under way to better understand human exposure to pesticides of concern through coordinated human biomonitoring under the Horizon 2020 project HBM4EU ([a]).

In terms of effects on ecosystem services that support health, neonicotinoids pose risks to wild bees and honeybees, important pollinators supporting food production (EFSA, 2018).

Note: ([a]) www.HBM4EU.eu

Box 4.21 Human biomonitoring to understand exposure

Human biomonitoring measures the concentrations of chemicals or their metabolites in human urine, blood, hair or tissue. It enables an assessment of human exposure to single chemicals or chemical mixtures resulting from the sum of chemicals that have entered the body via various external exposure pathways. It can be used to assess trends in human exposure to chemicals over time, allowing researchers to understand how risk management measures, such as restrictions, influence exposure.

Under the European human biomonitoring initiative, HBM4EU ([a]), efforts are under way to generate robust and coherent data sets on the exposure of the European population to chemicals of concern. This includes producing exposure data on 16 substance groups, mixtures of chemicals and emerging chemicals, as well as exploring exposure pathways and linking exposure to health effects.

Note: ([a]) www.HBM4EU.eu

Exposure to lead and cadmium has been associated with low socio-economic status in Belgium (Morrens et al., 2012) and Spain (Llop et al., 2011). Exposure may occur from lead-based paints or lead plumbing in older houses. Possible underlying factors for cadmium include diet and exposure to tobacco smoke, since cadmium is present in tobacco leaves. Even in women that smoke, the consumption of offal contaminated with cadmium can be an important contributor to the cadmium body burden (Berglund et al., 2015). Iron deficiency due to an unbalanced food pattern in groups with low social status may enhance the uptake of heavy metals such as cadmium (Kim et al., 2015). Living in an industrial hotspot (Wilhelm et al., 2005) and in older houses (Shiue and Bramley, 2015) can also drive differences in cadmium exposure by social status. In the Vitebro province, Italy, populations were found to be exposed to arsenic via drinking water, with higher arsenic exposure associated with low socio-economic status. This exposure was, in turn, associated with several diseases, including lung cancer, myocardial infarction, peripheral arterial disease, chronic obstructive pulmonary disease and diabetes (D'Ippoliti et al., 2015).

People with lower social status in terms of either income or education were found to have higher concentrations of certain phthalate metabolites in Belgium (Geens et al., 2014), the Netherlands (Ye et al., 2008) and Spain (Valvi et al., 2015). In Sweden, phthalate exposure in mothers and children was associated with the polyvinyl chloride (PVC) covering of floors and walls, with higher concentrations seen in less educated groups (Larsson et al. 2010). Children with PVC floorings in their bedroom were more likely to develop doctor-diagnosed asthma because of exposure via indoor dust (Shu et al., 2014). Other studies have found the social gradients for phthalates exposure to vary depending on the substance.

However, people of higher social status have also been found to have higher body burdens of certain chemicals. Raised concentrations of PFASs have been found in people of higher socio-economic status. This is linked to consuming food that has been contaminated via environmental sources or food contact materials and may also be influenced by the use of textiles and sport equipment containing PFASs. A recent study of mother-child pairs in six European countries found that higher socio-economic position was associated with higher concentrations of several chemicals during pregnancy and in children, including certain PFASs, mercury, arsenic, several phenols and organophosphate pesticides. Conversely, cadmium exposure during pregnancy and exposure to lead and phthalate metabolites in childhood were lower in this group (Montarezi et al., 2019). Increased concentrations of mercury and arsenic were found in individuals of higher socio-economic status in Austria (Gundacker et al., 2006), Ireland (Cullen et al., 2014) and Spain (Ramon et al., 2011). The consumption of large predatory fish and shellfish is associated with a higher mercury body burden (Castaño et al., 2015), with people of higher social status tending to consume more fish.

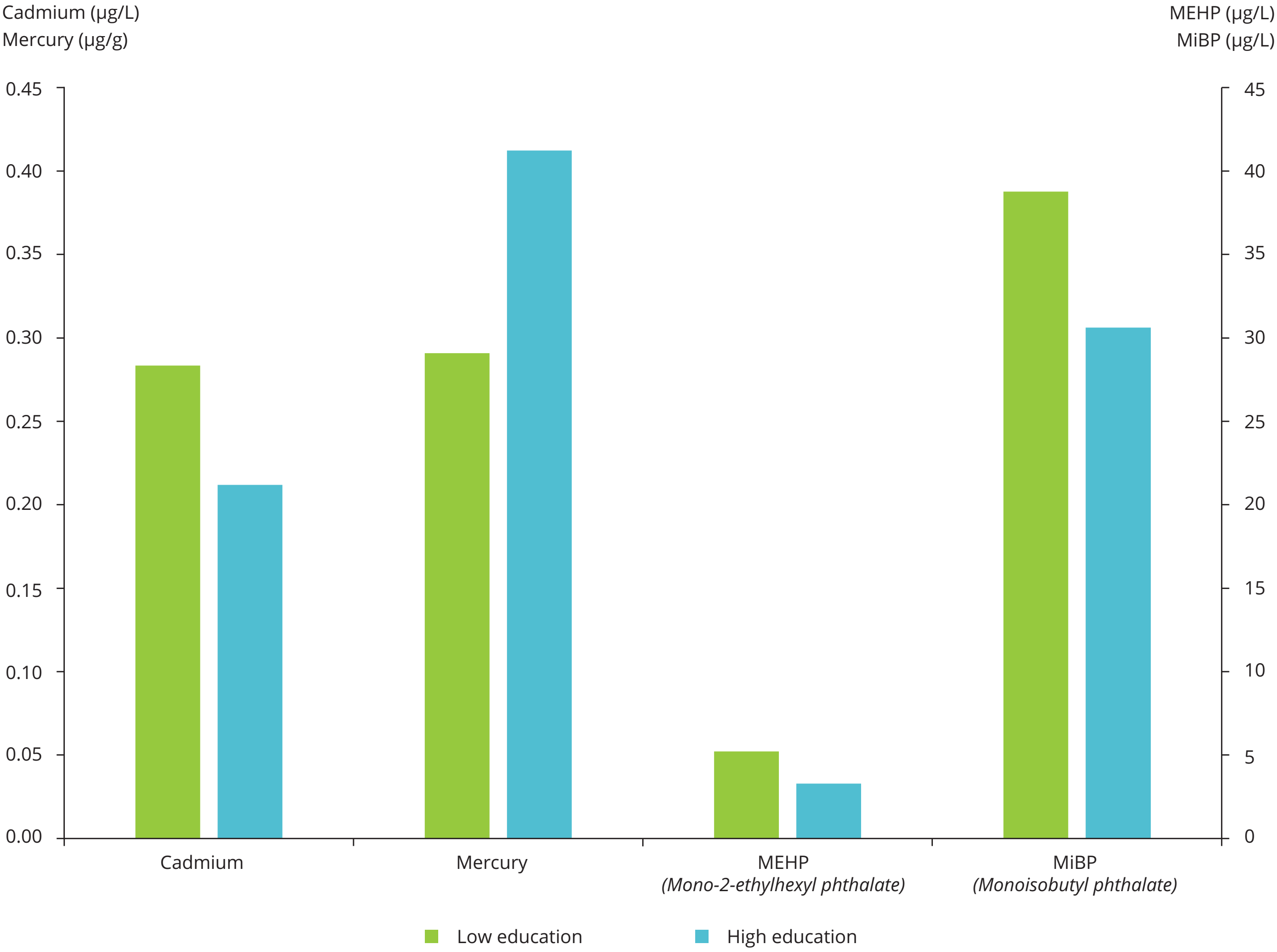
There is also some evidence from case studies that living close to industrial installations can result in exposure to chemical emissions. Residential location is linked to socio-economic status, with housing in proximity to industrial sites tending to be cheaper. A German study found higher blood levels of lead and cadmium among children living in the vicinity of metal refineries in North Rhine Westphalia (Wilhelm et al., 2005). A recent study estimated the health impacts 1 544 waste landfill sites on local populations across Europe and estimated that a total of 61 325 DALYs annually were associated with health outcomes including low birth weight (10 192 DALYs), congenital anomalies (958 DALYs), respiratory diseases (2 688 DALYs), and annoyance from odour (47 505 DALYs) (Shaddick et al., 2019). The case study presented in Section 4.5 describes drinking water contamination in Italy resulting from hotspot pollution.

Level of education as a factor in exposure to chemicals across 17 countries

The Democophes project monitored chemicals in 1 844 children and 1 844 mothers from 17 European countries (Den Hond et al., 2015). For this report, data from the Democophes project were analysed to assess how level of education influences exposure to mercury, cadmium and phthalates. The difference in chemical body burden was stratified by the highest education level in the family, building on the analysis undertaken by Den Hond et al. (2015). Stratification for socio-economic status at the country level results in small groups, meaning that results must be interpreted with caution. Nevertheless, consistent trends were observed across participating countries.

Figure 4.14 presents the average concentrations for a number of substances in mothers across all 17 countries, by education level. Overall, cadmium and the two phthalates — MEHP ([17]) and MiBP ([18]) — were higher in the group with lower educational attainment, while mercury was higher in the more educated group.

Figure 4.14 Average concentrations of mercury, cadmium, MEHP and MiBP in mothers, by low and high education levels, 2011-2012



Note: Low and high education levels can represent different education categories across countries.

Sources: Data are taken from Democophes country-specific statistical analysis reports, provided by the Belgian Federal Public Service of Health, Food Chain Safety and Environment (coordinating beneficiary of the Democophes project LIFE09/ENV/BE000410, co-funded by the LIFE programme and the participating countries). The reports are unpublished but available on request from the Belgian Federal Public Service of Health, Food Chain Safety and Environment.

([17]) Mono-2-ethylhexyl phthalate.
([18]) Monoisobutyl phthalate.

Box 4.22 Human exposure to phthalates and health

Phthalates are a group of industrial chemicals that are widely used as plasticisers to soften polyvinyl chloride (PVC) plastic for use in a wide range of consumer goods, such as vinyl flooring, adhesives, detergents, air fresheners, lubricating oils, food packaging, clothing, personal-care products and toys. Some phthalates are used as coatings on pharmaceuticals, herbal preparations and nutritional supplements.

In terms of health effects, certain phthalates ([a]) are classified as toxic to reproduction, meaning that they may damage human fertility and cause harm to an unborn child. In addition, some phthalates ([b]) are known to be endocrine disruptors. Epidemiological studies have associated exposure to certain phthalates with obesity, insulin resistance, asthma, early onset of puberty, attention deficit disorder and attention deficit hyperactivity disorder. Mixtures of phthalates with similar properties can be more toxic than each individual chemical in isolation.

Humans are exposed to phthalates through the consumption of foods and drinks held in containers containing phthalates. Children can be exposed by sucking on plastic toys or products that contain phthalates. Another potential exposure route is indoor dust contaminated with phthalates released from plastic products or PVC furnishings.

Risk management measures are in place across the EU to minimise exposure to phthalates known to be hazardous to health.

- Several phthalates (di-2-ethyhexyl phthalate, DEHP; benzyl butyl phthalate, BBzP; diisobutyl phthalate, DiBP; and di-n-butyl phthalate, DnBP) cannot be used in the EU without authorisation for specific uses.
- DEHP, DnBP, DiBP and BBzP are banned in all toys and childcare articles, while diisononyl phthalate (DINP), diisodecyl phthalate (DIDP) and di-n-octyl phthalate (DNOP) are banned in toys and childcare articles that can be placed in the mouth.
- The use of phthalates classified as toxic to reproduction is prohibited in cosmetics, apart from in exceptional cases.
- The EU is currently setting legal limits for the concentration of certain phthalates (DEHP, BBzP and DnBP) in materials intended to come into contact with food.
- The use of diisopentyl phthalate (DiPeP), di-n-pentyl phthalate (DnPeP), isopentyl-n-pentyl phthalate (PIPP) and di(methoxyethyl) phthalate (DMEP) is banned in consumer products on the EU market.

Efforts are under way to further restrict the use of certain phthalates in the EU. However, older products and furnishings in people's homes and workplaces may contain phthalates that are now banned. Phthalates with hazardous properties are therefore still present in our everyday environment.

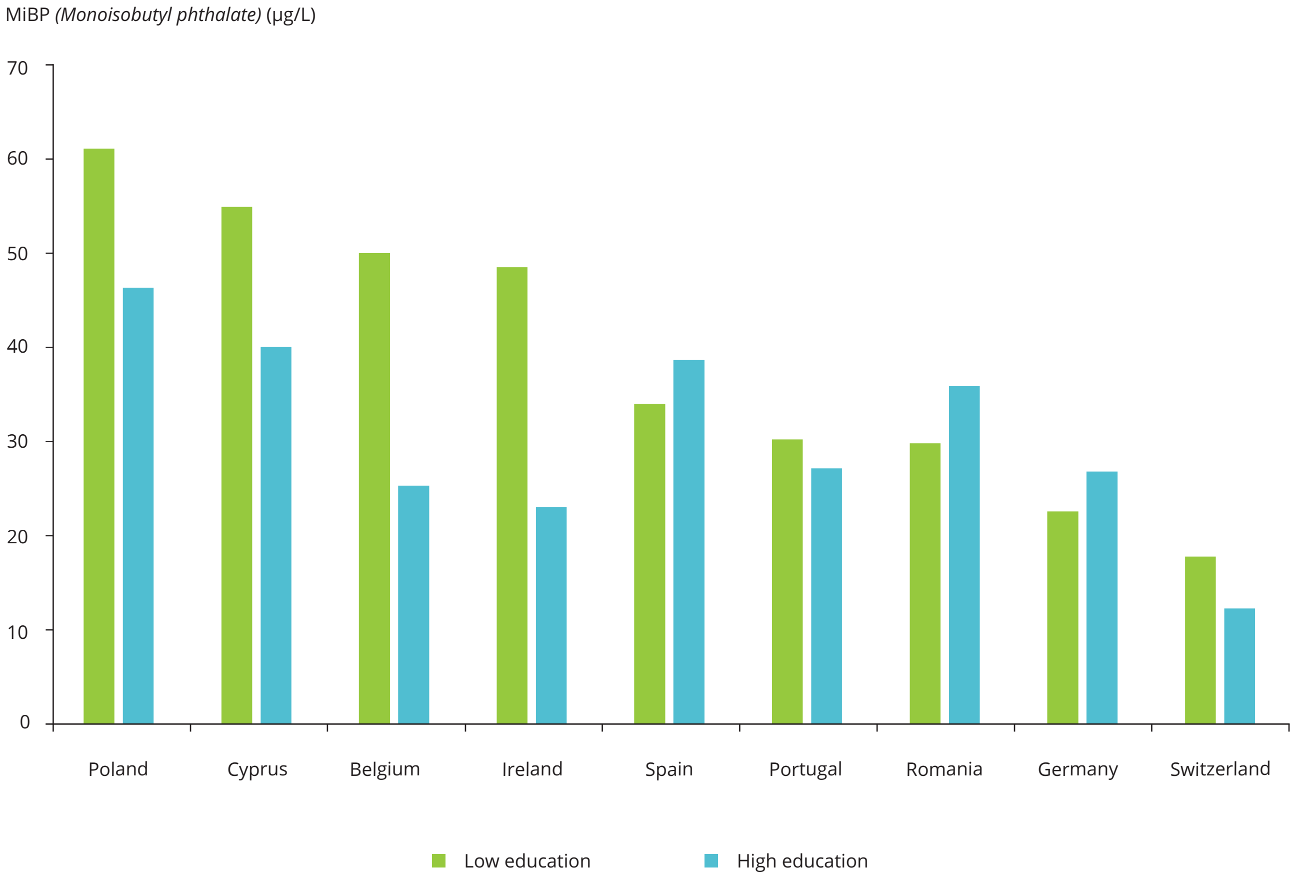
Notes: ([a]) The following phthalates have been classified in the EU as toxic for reproduction: DEHP; benzyl butyl phthalate, BBzP; di-n-butyl phthalate, DnBP; diisobutyl phthalate, DiBP; dicyclohexyl phthalate, DCHP; di-n-pentyl phthalate; diisopentyl phthalate, DiPeP; di(methoxyethyl) phthalate, DMEP; isopentyl-n-pentyl phthalate, PIPP; di-n-hexyl phthalate, DnHP; 1,2-benzenedicarboxylic acid dipentyl ester, branched and linear.

([b]) The following phthalates have been classified in the EU as endocrine-disrupting compounds: DEHP, BBzP, DnBP, DiBP and DCHP.

Focusing on the individual chemicals allows us to explore some of the social drivers behind exposure. For phthalates (see Box 4.22), the results of the analysis by educational status vary across countries and the phthalate studied. MEHP, a metabolite of DEHP ([19]), was consistently higher in mothers from families with lower educational levels, with the sole exception of Spain. Likewise, higher internal exposure to the diisobutyl phthalate (DiBP) metabolite MiBP was seen in less educated mothers in five of the nine participating countries, as shown in Figure 4.15. DiBP is a phthalate used in paint, lacquers, varnishes, paper, adhesives, paper and packaging for food and bottled water. For other phthalates, associations between exposure and levels of education were less consistent.

([19]) Di-2-ethyhexyl phthalate.

Figure 4.15 Concentrations of the DiBP metabolite MiBP in the urine of mothers, 2011-2012



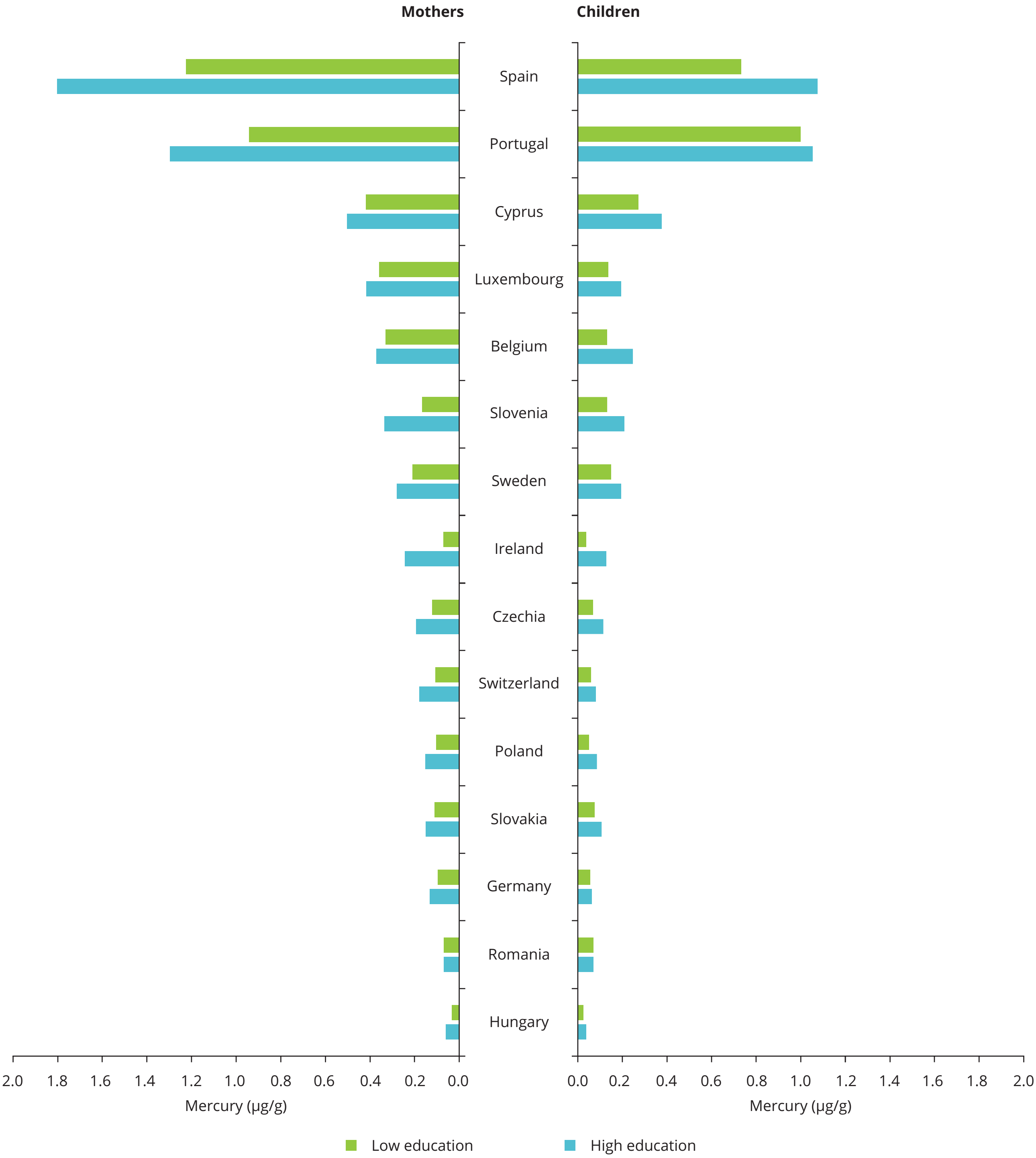
Sources: Data from Democophes country-specific statistical analysis reports.

Figure 4.16 presents the differences in the concentrations of mercury in the hair of mothers and children between families with the highest level of education and those with the lowest level of education. Across all 17 EU countries, mercury levels in hair were higher in both children and their mothers when the family had higher levels of educational attainment (Den Hond et al., 2015). This is linked to higher levels of fish consumption among higher socio-economic groups. The largest difference between educational levels is seen in Ireland, although mercury concentrations were not extremely high or low in Ireland. See Box 4.23 for a discussion of the health impacts of human exposure to mercury in Europe.

As a final example, cadmium is a highly toxic metal affecting kidneys and bones and is linked to lung cancer, cardiovascular disease, hormone-related cancer and developmental effects in children. The principal exposure route is smoking. For non-smokers, the consumption of food grown or raised in soil contaminated with cadmium is the main exposure pathway. Soils may be contaminated by industrial activity or through fertilisers that contain cadmium. A recent WHO report analysed the Democophes data and found that, in 10 out of 15 countries, the cadmium body burden of mothers and children increased with lower levels of education (WHO Europe, 2019a). The largest differences were observed in countries where absolute cadmium concentrations were highest, implying that there are opportunities to reduce exposure.

This review of the available evidence demonstrates the role of social dimensions, including diet, smoking, housing conditions, residential area and behaviours, in influencing internal chemical exposure. The influence runs both ways, with a bias towards higher or lower social groups, depending on the specific chemical. Further research is required to better understand how social status drives exposure to different chemicals, as a basis for informing measures targeted at reducing exposure amongst vulnerable groups.

Figure 4.16 Mercury concentrations in the hair of mothers and children, 2011-2012



Sources: Data from Democophes country-specific statistical analysis reports.

Box 4.23 Human exposure to mercury and health impacts in Europe

Mercury is a persistent, bioaccumulative and toxic pollutant that is naturally present in the environment and also released by human activity (EEA, 2018e). Mercury affects the nervous system, kidneys and lungs, and foetal exposure affects the development of the brain and nervous system. High levels of exposure can result in symptoms such as vision and hearing problems and delays in language development and memory. The principal route of human exposure to mercury is diet, which is due to the bioaccumulation of methylmercury in the food chain, in particular in large predatory fish species (e.g. marlin, swordfish and tuna).

The Democophes human biomonitoring study found the highest mercury body burdens in countries with higher levels of fish consumption (Den Hond et al., 2015). Using the Democophes data, it was estimated that, every year in Europe, nearly 1.9 million babies are born with mercury levels above a recommended safe limit, i.e. approximately one third of all births. Countries with higher levels of large predatory fish consumption were estimated to have proportionately more babies born with mercury levels above the limit. The potential impact on children's brain development is lifelong and can result in significant cognitive impairment with related economic costs (Bellanger et al., 2013).

Dietary exposure to mercury can be managed through dietary advice (Castaño et al., 2015), provided at a national level in EU Member States (EEA, 2018d). For example, a Danish study (Kirk et al., 2017) offered pregnant women dietary advice to help them lower their mercury intake without reducing their fish consumption by avoiding large predatory fish. The women completed a questionnaire on their dietary habits, including fish intake, and an initial sample of their hair was taken for mercury analysis. Based on the initial sample, 22 % of the women had mercury levels above the safe limit. A sample taken 3 months later saw this reduced to 8 %, with a significantly lower average mercury level seen across all participants. The overall fish consumption levels remained constant, indicating that the changes in mercury levels resulted from consuming less predatory fish.

4.7 Indoor air quality and health

Key messages:

- Indoor air can be polluted with a mixture of ambient air pollutants, hazardous chemicals, radon and moulds, leading to significant health impacts.
- An estimated 2 million disability-adjusted life-years are lost annually in the EU because of poor indoor air quality, driven mainly by particulate matter.
- Air quality in buildings results from a complex interplay between building quality and ventilation, outdoor air quality, and emissions from burning solid fuels, cleaning and consumer products and smoking.
- Groups vulnerable to poor indoor air quality include children and the elderly. Improving air quality in schools, in particular, offers significant health gains.
- Efforts to improve indoor air quality require an integrated approach, including building design and management, product standards and education to foster positive behaviours.

With people spending up to 90 % of their time indoors (Vardoulakis et al., 2015), air quality inside homes, offices, schools, nurseries, healthcare facilities and other buildings is an important health determinant. Indoor air quality is affected by pollutants brought into buildings from outside, as well as pollutants originating indoors. Figure 4.17 depicts the various potential sources of indoor air pollution, while Box 4.24 identifies policies that contribute to indoor air quality.

Box 4.24 Policies contributing to indoor air quality

Policy frameworks explicitly tackling indoor air pollution are, for the most part, lacking at the European level. There are no monitoring requirements for indoor air quality in the EU, meaning that there is no consolidated data set at the European level.

Regarding buildings, European standards are in place for the ventilation of buildings, EN 1506. The Energy Performance of Buildings Directive (EU, 2010) aims to promote the health and well-being of building users through increased consideration of air quality and ventilation.

Chemical legislation also has an impact on indoor air quality, including the Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation (EU, 2006b), which regulates market access for industrial chemicals and policies limiting the use of chemicals in products, such as Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment (EU, 2011).

The World Health Organisation has issued reports that address indoor air pollution, including:

- *WHO guidelines for indoor air quality: dampness and mould* (WHO Europe, 2009a);
- *WHO guidelines for indoor air quality: selected pollutants* (WHO Europe, 2010);
- *WHO guidelines for indoor air quality: household fuel combustion* (WHO, 2014).

The 2016 Commission Recommendation 2016/1318 on the promotion of nearly zero-energy buildings also includes a specific reference to indoor air quality issues, stating that a proper indoor environment should be ensured to prevent the deterioration of indoor air quality, comfort and health conditions in the European building stock (EC, 2016c).

Figure 4.17 Sources contributing to indoor air pollution

1/Particulate matter, nitrogen dioxide and ozone

The use of solid fuels such as coal, wood or other biomass, for *cooking* and for **residential heating** releases particulate matter. Ambient air polluted with particulate matter, ozone and/or nitrogen dioxide enters buildings via **open window and gaps in the walls.** Air pollution causes irritation of eyes, nose and throat, can cause breathing difficulties and is associated with non-communicable diseases.

2/Synthetic chemicals

Cleaning products contain chemicals that pose known or suspected hazards to health. **Plastic products** release plasticisers into air and dust as they degrade. **Electronic and electrical equipment, textiles and furniture** contain flame retardants, with older products likely to contain chemicals now banned from use in Europe. Products containing perfume, such as **air fragrance, personal care products and scented candles**, release endocrine disruptors.

3/Biological pollutants

Fungi, such as moulds, and bacteria grow in **moist building materials**. Mycotoxins released from fungi have carcinogenic, immunotoxins, cytotoxic and mutagenic effects.

4/Radon

The radioactive gas radon occurs naturally in certain **rocks and soil** and can infiltrate into houses. Inhaling radon gas damages the lungs and can cause lung cancer.

5/Tobacco smoke

Indoor **tobacco consumption** exposes all household members to secondary tobacco smoke. Exposure to **second-hand smoke** is associated with chronic obstructive pulmonary heart disease and chronic respiratory disease, with particularly severe implications for children.

Source: EEA and JRC (2013).

4.7.1 Health impacts of indoor air pollution

Exposure to indoor air pollution is associated with a number of non-communicable diseases. An estimated 2 million DALYs are lost annually in the EU because of poor indoor air quality (Asikainen et al., 2016). Exposure to indoor air pollution is estimated to reduce productivity and learning by up to 15 %. In France, it has been estimated that the annual cost of indoor air pollution relating to premature deaths, healthcare and production losses comes to approximately EUR 20 billion for six pollutants, equating to 1 % of total French GDP (Boulanger et al., 2017). Fine PM ($PM_{2.5}$) contributes the largest fraction.

Estimates of deaths attributable to household air pollution by disease group are presented in Table 4.4 for the EU-28, the EEA-33 and the EEA-33 plus Albania, Bosnia and Herzegovina, Kosovo, North Macedonia and Serbia (EEA-39). The principal diseases resulting in deaths attributable to household air pollution are ischaemic heart disease, cancers and strokes, similar to the diseases driving mortality from ambient air pollution. These data from the WHO Global Health Observatory focus on exposure to indoor smoke from the use of solid fuel for cooking, which is not very common in most EU countries. The use of solid fuel for cooking may explain the significant increase in attributable deaths when the West Balkan countries under the EEA-39 were included.

For many countries, zero deaths were attributable to household air pollution. This explains why the figures for the EEA-33 and the EU-28 are the same, since the non-EU EEA member countries Norway, Switzerland and Iceland had no deaths, while there were no data for Turkey and Lichtenstein.

Sick Building Syndrome describe situations in which occupants experience acute health effects and discomfort linked to spending time in a building, with no specific illness diagnosed (Chirico et al., 2017). There may be links between Sick Building Syndrome and indoor air quality (Jafari et al., 2015). Indoor pollutants known to pose health risks are discussed in turn below.

PM, NO_2 and ozone

Ambient air polluted with NO_2, ozone and/or PM can enter buildings via cracks and gaps in the exterior walls of the building or via open windows, affecting the health of people in the building, as described in Section 4.1. It is estimated that almost 80 % of the burden of disease from indoor exposures is caused by exposure to $PM_{2.5}$ in the EU (Asikainen et al., 2016). Important indoor sources of PM include candles and the cooking and burning of solid fuels such as coal, wood or other biomass (Isaxon et al., 2015). Evidence suggests that indoor PM may be more bioactive than ambient particles because of the presence of endotoxins and other pro-inflammatory components in indoor particles (EC and JRC, 2012).

Evidence that climate change exacerbates indoor air pollution is considered in Box 4.25.

Table 4.4 Deaths attributable to household air pollution by disease, EU-28, EEA-33 and EEA-39, 2016

	Deaths attributable to household air pollution		
Disease	**EU-28**	**EEA-33**	**EEA-39**
Ischaemic heart disease	6 062	6 062	10 237
Trachea, bronchus, lung cancers	2 280	2 280	4 375
Stroke	2 937	2 937	5 671
Lower respiratory infections	1 686	1 686	2 245
Chronic obstructive pulmonary disease	1 693	1 693	3 127
Total	**14 659**	**14 659**	**25 653**

Note: Data for the EEA-39 exclude data for Lichtenstein, Kosovo and Turkey because no data are available; data for the EEA-33 exclude data for Lichtenstein and Turkey because no data are available.

Source: WHO (2018b).

Box 4.25 Climate change and indoor air pollution

- Warmer summer temperatures may lead occupants to open windows more often, coinciding with periods of high outdoor ozone levels and resulting in increased indoor exposure.
- Energy efficiency interventions to reduce ventilation may lead to the accumulation of indoor air pollutants.
- Climate change is likely to increase ambient dust levels as a result of drier weather conditions in many areas of Europe and cause associated increases in dust levels inside buildings.

Source: Vardoulakis et al. (2015).

Radon

Another outdoor factor causing indoor air pollution is radon — a natural occurring radioactive gas that permeates up from the ground — the source of which is naturally occurring radioactive elements in certain soil and rock formations. Across Europe high radon concentrations occur naturally in the Bohemium Massif of Czechia, in the Iberian Peninsula across Spain and Portugal, in the Massif Central of southern France and in Cornwall, United Kingdom. In France, exposure to radon is the second leading cause of lung cancer after smoking, with between 1 000 and 5 000 deaths attributable to radon each year (Ajrouche et al., 2018). In the United Kingdom, radon is the largest natural source of human exposure to ionising radiation. Once detected, radon is relatively easy to address through the installation of radon barriers or sumps.

Hazardous chemicals

In terms of exposure to hazardous chemicals in indoor air, concerns focus on chemical additives in plastic consumer goods, volatile organic compounds (VOCs) in building materials and flame retardants in furniture, building materials and electrical goods. People are exposed by breathing in contaminated air or by inhaling contaminated dust particles. Young children crawl on the ground where they can be exposed to dust and chemicals that accumulate on the floor.

Chemicals used as plasticisers, such as bisphenols (including BPA; and the substitutes bisphenol S, BPS, and bisphenol F, BPF) and phthalates, are released into the air in small amounts as plastic degrades and are collected in dust. Although European data are scare, Larsson et al. (2017) found phthalates, non-phthalate plasticisers and bisphenols in dust from 100 Swedish preschools. The levels of several substitute plasticisers were higher in newer preschools, whereas the levels of the strictly regulated phthalate, di-n-butyl phthalate (DnBP), were higher in older preschools. Nevertheless, the children's exposure from ingesting preschool dust was below relevant health-based reference values.

VOCs, such as formaldehyde and benzene, are emitted from building materials, furniture and paints and may cause significant health effects. The short-term consequences include skin irritation, dizziness and nausea, while in the longer term some VOCs are carcinogenic (Duarte-Davidson et al., 2001). Children exposed to concentrations of VOCs higher than 60 μg/m^3 have a fourfold increase in the risk of developing asthma (Rumchev et al., 2007).

A large group of chemicals known as flame retardants have been used to lower the flammability of products, furniture and construction materials. Some, such as PBDEs, have been linked to neurotoxicity through endocrine disruption (Eskenazi, et al., 2013).
The economic costs of losses in IQ (Intelligence Quotient) due to exposure to PBDEs are estimated at EUR 11 billion (Grandjean and Bellanger, 2017). PBDEs are now restricted at the EU level and under the Stockholm Convention, and this has driven their replacement with substitutes, known as emerging flame retardants.

A review of children's exposure to flame retardants found high concentrations of legacy PBDEs in dust from houses, kindergartens and primary schools in Europe (Malliari and Kalantzi, 2017). Human biomonitoring studies that measured brominated and/or phosphorylated flame retardants in toddlers' (8- to 24-month-olds) serum, urine, hand wipes and faeces found that toddlers were exposed to a range of flame retardants associated with thyroid disruption. Exposure is linked to the indoor environment, via products such as plastic toys (Sugeng et al., 2017). The few studies that have looked at both legacy and emerging flame retardants in indoor air in the United Kingdom (Tao et al., 2016) and Spain (Reche et al., 2019) have detected lower levels of legacy flame retardants and higher concentrations of emerging flame retardants, indicative of progressive substitution. However, evidence is now emerging of the health concerns associated with some emerging flame retardants.

Older construction materials and products with longer lifecycles may contain hazardous chemicals that are now controlled. For example, older furniture may contain legacy flame retardants that are now banned, such as PBDEs. Similarly, the now-banned polychlorinated biphenyls (PCBs) were widely used in construction materials in the 1970s and 1980s and can be present in indoor air (Gunnarsen, et al., 2017). PCBs have been linked to cancer, immunosuppression and endocrine and reproductive disorders (UNEP and AMEP, 2011). An example of efforts to reduce chemical emissions to air in Denmark is provided in Box 4.26.

Biological pollutants

Damp and mould also pose health risks in indoor settings. Mould and bacteria accumulate when moisture levels are adequate, and this is exacerbated by poor ventilation. When spores become part of the air humans breathe, there are increased risks of allergic and hypersensitivity reactions, exposure to toxins and infections (Vardoulakis et al., 2015). Fungi can produce over 300 different mycotoxins, thought to have carcinogenic, immunotoxins, cytotoxic and mutagenic effects (Gutarowska and Piotrowska, 2007).

Tobacco smoke

The health impacts of tobacco smoking are well documented; yet, across Europe a large proportion of the population continue to be exposed to second-hand smoke. More than one in four people who work indoors are exposed to second-hand smoke at work (Filippidis and Vardavas, 2017). Exposure to second-hand smoke is associated with chronic obstructive pulmonary heart disease and chronic respiratory disease, with particularly severe implications for children (Jordan et al., 2011; Wang et al., 2015). The rising consumption of e-cigarettes must be factored into future indoor air quality issues, a behaviour for which the health impacts remain largely unknown (Callahan-Lyon, 2014).

Combined exposure

It is clear from the discussion above that indoor air can contain a broad range of pollutants, including chemicals, allergens and microbes that may have combined impacts on health. For example, there is evidence to suggest that chemical air pollution may interact with airborne allergens to enhance the symptoms of those who are pre-disposed to specific allergies and asthma (Baldacci et al., 2015). Mixtures of hazardous chemicals that have similar health effects can have an impact on human health in an additive or synergistic fashion. However, the complexity of indoor air and its variability over time and location make generalised risk assessments extremely challenging.

Solutions for improving indoor air are considered in Box 4.27.

Box 4.26 Danish emissions labelling scheme

The voluntary material emission labelling scheme 'Danish Indoor Climate Labelling' was established in 1993. The purpose of scheme is to:

- improve the air quality in buildings by documenting the impact of products on indoor air quality;
- contribute to the development of indoor friendly products;
- support the selection of indoor friendly products.

Originally intended for building products, the scheme now also covers furniture, fixtures and fittings, with active labelling licences issued for more than 3 000 individual products. The labelling scheme has proved to be useful in several ways. There is now an increased focus on low emitting materials; there has been a tendency towards generally lowered emission levels among the labelled products over the years; and in many cases test results have been used actively for product development.

Source: Dansk Indekilma Markning (2018).

Box 4.27 Solutions for improving indoor air quality

The **EnVIE** project developed a modelling tool to evaluate the relationship between indoor air quality-related diseases and exposures and the impact of policy control measures (EC, 2012b).

The follow-on project, 'Promoting actions for healthy indoor air (IAIAQ)', produced the **EnVIE-IAIAQ** modelling tool and provides an update of the potential impact that policy actions might have on indoor air quality and health (Jantunen et al., 2011).

The **HEALTHVENT** project (Health-Based Ventilation Guidelines for Europe, 2008-2013) developed guidelines for health-based ventilation rates and recommended the implementation of mechanical ventilation, to filter outdoor air if it does not meet existing air quality guidelines (Fernandes et al., 2015).

Improving building ventilation offers a means of tackling indoor air pollution, for example Almeida-Silva et al. (2014) found that concentrations of common pollutants exceeded limit values in an elderly care home because of poor ventilation. Higher ventilation rates in offices reduce the prevalence of Sick Building Syndrome, while home ventilation rates are associated with reduced allergy symptoms in children (Sundell et al., 2011). Current technology tends to circulate the air inside buildings, reducing air quality (Spiru and Simona, 2017). The burden of disease from indoor air pollution could be reduced by improving ventilation, filtering air as it moves into a building, sealing buildings and reducing the pollution caused by indoor sources. It is estimated that this could reduce the health risks of indoor air pollution from 2 million disability-adjusted life-years (DALYs) to between 400 000 and 900 000 DALYs in the EU (Asikainen et al., 2016).

There are calls for new building designs to deliver a 'smart home', with advanced sensor technology offering greater living comfort and health (Schieweck et al., 2018).

4.7.2 Vulnerable groups

Vulnerable groups and indoor air pollution

Certain groups are particularly susceptible to the effects of indoor air pollution. Vulnerable groups such as children (see Box 4.28), the elderly and people exhibiting poor health are concentrated in kindergartens, retirement homes and hospitals, respectively (EEA and JRC, 2013). People with asthma, cardiovascular disease or respiratory disease are particularly vulnerable to indoor air pollution (Cincinelli and Martellini, 2017).

Socio-economic aspects of indoor air pollution

There is some evidence to suggest that there is a socio-economic dimension to indoor air pollution exposure. This is likely to be exacerbated by the link between lower socio-economic status and poor building quality, which increases the chances of poor ventilation, leading to mould and damp (WHO Europe, 2009b).

The use of solid fuel boilers or heaters exacerbates both indoor and ambient air pollution from local heating. While the EU has set standards to improve the efficiency of such devices under the Ecodesign Directive (EU, 2009b), these standards will only come into force for new devices in 2022. Residential combustion is a particularly significant source of $PM_{2.5}$ in central Europe (EEA, 2018b). Replacing inefficient heating devices, often owned by low-income families, is a major challenge for citizens and some Member State authorities. For example, in the Polish region of Małopolska, the anti-smog resolution under the region's air quality plan restricts the use of solid fuels, with the aim of achieving compliance with air pollution limit values by 2023 (Małopolska Region, 2019). At the same time, the cost of replacing residential heating sources was estimated at over EUR 1 billion, with no national funding available (European Court of Auditors, 2018).

The effect that low socio-economic status has on the increased exposure of children to adult second-hand cigarette smoke is also becoming clear (Bolte and Fromme, 2009). In 2011, it was found that it was 11 times more likely for a child to be exposed to second-hand smoke at home if their parent/s had a low level of education than if they had a high level of education (Pisinger et al., 2012).

Box 4.28 Indoor air quality in schools

Children spend large amounts of time indoors and are particularly susceptible to the health effects of indoor air pollution. In Europe, 64 million students and almost 4.5 million teachers spend many hours each day in schools and kindergartens. Indoor air quality in school buildings can negatively affect the health, attendance and performance of children, teachers and school staff.

The Schools Indoor Pollution and Health Observatory Network in Europe (Sinphonie) is an EU-funded research project that collected information on indoor air quality and children's health from schools in 25 European countries (EC, 2014). Particulate matter with a diameter of 2.5 μm or less ($PM_{2.5}$), volatile organic compounds, radon and biological agents were commonly detected in classrooms, sometimes in elevated concentrations above existing guideline values proposed by the EU and the World Health Organisation (WHO).

Indoor air quality in school buildings is influenced by outdoor air pollution, the age of the school buildings, location, cleaning, maintenance and ventilation strategies. The use of paints, glues and other products are also potentially important sources of indoor pollution. $PM_{2.5}$, nitrogen dioxide, ozone and noise contribute to pollution in schools, with 67 % of all schools monitored located by busy roads.

Recommendations include the following:

- Ambient air quality should meet WHO guidelines.
- Newly constructed schools should consider indoor air quality, chose clean construction materials and implement health-based ventilation.
- School building management procedures should consider the vulnerability of children.
- Awareness raising should be implemented for children, parents and school staff.
- When considering the total pollution burden on children, the school environment must be fully integrated.

Source: EC (2014).

4.8 Electromagnetic fields and health

Key messages:

- There are well-defined acute human effects of exposure to certain electromagnetic fields, including symptoms such as nerve and sensory organ stimulation and the heating of tissues.
- There is currently little scientifically established evidence of causal relationships between long-term exposure and reported symptoms, though in some cases there is certainly a clear need for further research.
- Given the limitations in the current evidence base and the expected increase in exposure of the European population to radio frequency electromagnetic fields following deployment of 5G, further research is needed regarding possible health effects.
- The World Health Organization is carrying out further research on electromagnetic fields exposure, to provide more comprehensive conclusions on the potential long-term health effects.

Electromagnetic fields (EMFs) are a combination of invisible electrical and magnetic fields of force. They are generated by natural phenomena, such as the Earth's magnetic field, but also by human activities, mainly the use of electricity (EC, 2009). EMFs are generated by many devices, such as mobile phones, televisions, power tools and electrical power lines. Certain applications deliberately use EMF, for example the use of static magnetic fields in magnetic resonance imaging for medical purposes.

There are two types of EMF: ionising and non-ionising radiation. Ionising radiation includes EMF of mid to high-frequency, such as ultraviolet rays, x-rays and gamma rays, the energy from which can damage human cells and cause cancer. Non-ionising EMFs are normally categorised based on the frequency of the field, typically:

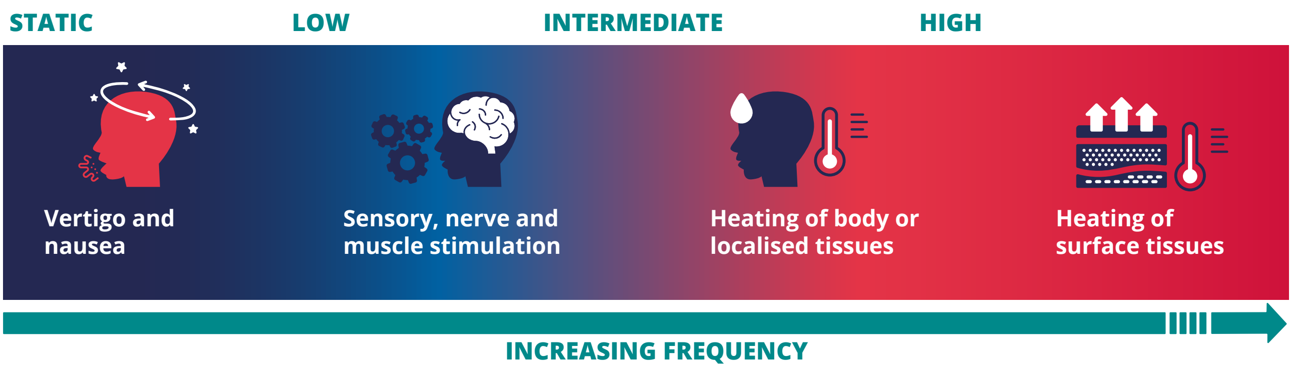
- radio frequency (RF — 100 kHz to 300 GHz);
- intermediate frequency (IF — 300 Hz to 100 kHz);
- extremely low frequency (ELF — 0 Hz to 300 Hz);
- static (0 Hz).

More recently, EMFs in the terahertz (THz) range have also become more widely used.

There are direct and indirect health effects of exposure to EMFs that are well understood. Direct effects at different frequency ranges are shown in Figure 4.18, and include non-thermal effects (such as the stimulation of nerves, muscles and sensory organs) and thermal effects (such as tissue heating). These effects are normally short term and transient and cease when the EMF is deactivated.

Indirect effects relate to situations in which the presence of an object within an EMF may cause a safety or health hazard (EC, 2015b). Indirect effects could include, for example, interference with implanted medical devices in the human body.

Figure 4.18 The effects of non-ionising EMFs in different frequencies



Note: Frequency intervals are not to scale.

Source: EC (2015b).

Box 4.29 Policies on EMF

In 1999, the Council of the European Union published a recommendation on the limitation of exposure of the general public to electromagnetic fields (EMFs) (Council of the European Union, 1999). This included recommended reference values for high voltage power lines of 5 kilovolts per metre for electric fields and 100 microteslas for magnetic fields. As this is a recommendation, it has not been applied in all EU Member States. Some countries have chosen to implement more stringent reference values. The different approaches taken by different Member States are illustrated in Map 4.9, which shows the variation in the limits for power frequency EMFs. There are also variations in the limits applied to radio frequency EMFs (not shown).

The EMF Directive was adopted in 2013 (EU, 2013b) to protect workers from both the direct and the indirect effects of EMFs in the workplace. The directive does not address the long-term effects of exposure to EMFs because of a lack of causal evidence of harm to health. If such evidence emerges, then the Commission will consider the necessary means for addressing such effects (EC, 2014).

In the European Commission’s 2016 communication on connectivity for a competitive digital single market, towards a European gigabit society (EC, 2016a), the deployment of very high capacity fifth generation telecommunications technologies (5G) across Europe by 2025 is identified as a critical building block of the digital economy and society. It sets 2025 connectivity targets for public service providers, transport hubs and major terrestrial transport routes, digital enterprises, and urban and rural households. Specifically, urban areas, major roads and railways should have uninterrupted 5G coverage. The 5G for Europe Action Plan (EC, 2016b) sets out measures for the timely and coordinated deployment of 5G across the EU. Adopted in 2018, the European Electronic Communications Code (EU, 2018) paves the way for the uptake of 5G across the EU. It recognises the need to ensure that citizens are not exposed to electromagnetic fields at levels harmful to public health, with Member States able to restrict the types of radio networks or wireless access technology to protect human health.

Current questions focus on the impact of rolling out the fifth generation of telecommunications technologies, known as 5G, intended to power the Internet of Things. Compared to previous generations of communications technology, 5G employs higher frequency radio waves that have shorter ranges, requiring a dense network of antennas and transmitters to deliver significantly improved connectivity. Such a dense network is predicted to result in constant exposure of the population to RF EMF, a form of non-ionising radiation, with some researchers expressing concerns regarding impacts on human health (Karaboytcheva, 2020).

Policies to address human exposure to EMF and to support the role out of 5G in Europe are presented in Box 4.29.

4.8.1 Longer term effects of exposure to EMFs

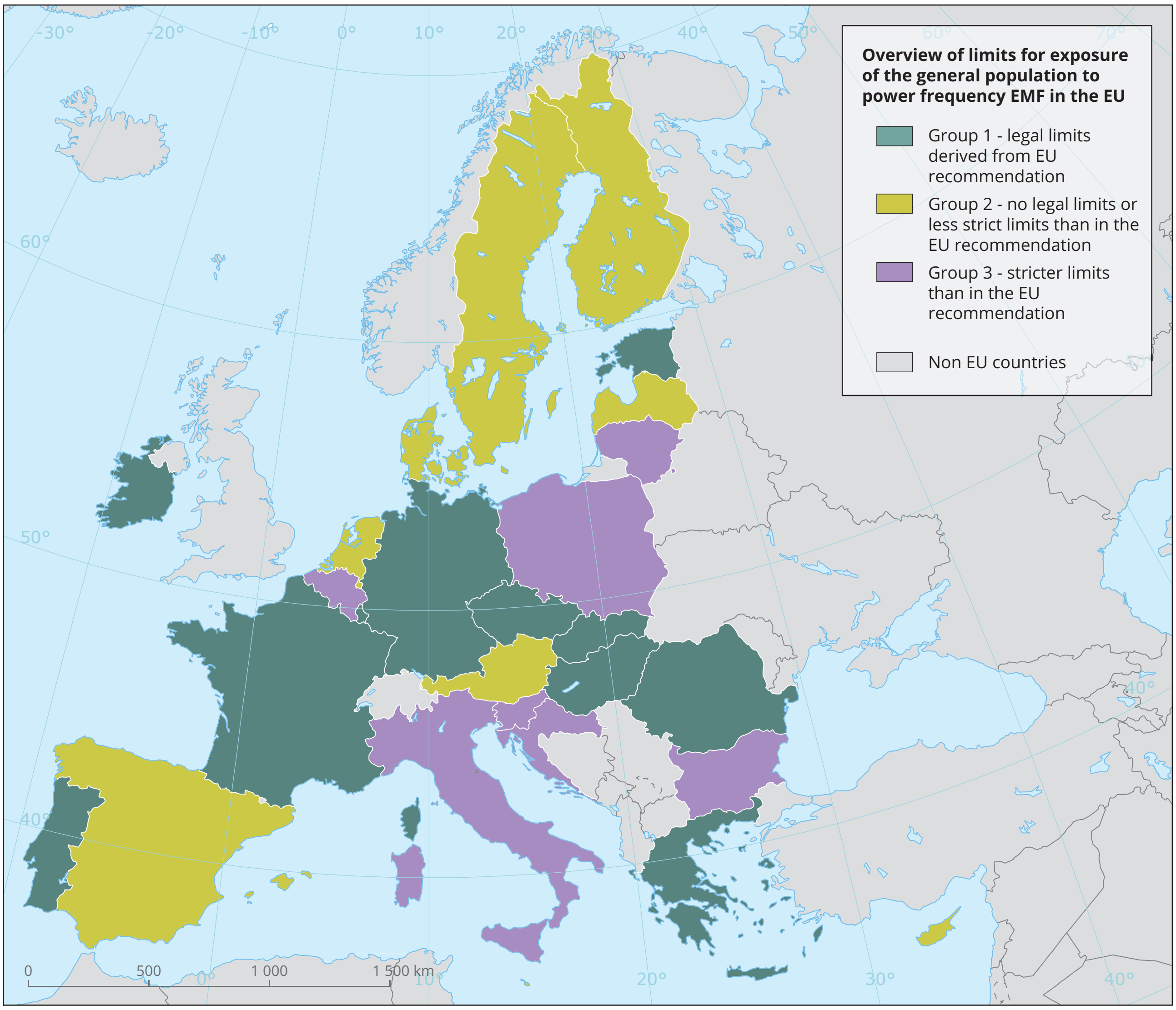
The European Commission Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) published an opinion on the potential health effects of exposure to EMFs (EC, 2015c). The report examines available evidence of the impacts from different frequencies of EMFs, with the conclusions broadly establishing that there is little convincing evidence of causal relationships between exposure and reported symptoms, though in some cases there is a clear need for further research.

There are a limited number of studies investigating the effects of very high frequency EMFs — THz EMFs — but they do not provide evidence of specific health impacts. The SCENIHR recommends that, as a result of the expected increase in use of THz technology, further research on its effects is necessary.

RF EMFs are associated with mobile phone usage, as well as the deployment of 5G, and are of particular interest to the public in terms of the potential health effects. In 2011, the International Agency for Research on Cancer (IARC) classified RF EMF as a possible human carcinogen, based largely on limited evidence of increased risks of gliomas and acoustic neuromas among long-term users of cell phones (IARC, 2011). In contrast, the 2015 SCENIHR report indicates that studies on mobile phone exposure do not show an increased risk of brain tumours or other cancers in the neck and head region. However, there is evidence that RF EMF exposure can affect brain activity when a person is awake and also during sleep, though the potential impacts of this are not clear. The report found a lack of evidence linking RF EMF exposure to impaired cognitive function, neurological diseases or reproduction and developmental effects (EC, 2015c).

A Danish review of more than 28 000 children found that an elevated risk of behavioural problems was associated with both the mother's and the child's own mobile phone use (Divan, 2012). In this study,

Map 4.9 **Overview of limits for exposure of the general population to power frequency EMFs in the EU**



Source: RIVM (2018).

exposure to mobile phones was also associated with lower socio-economic status, maternal smoking and the younger age of mothers, which slightly weakened the strength of the association between exposure and the prevalence of behavioural problems.

More recently, in a 2018 statement on emerging environment and health risks, the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) highlighted the potential effects of increases in electromagnetic radiation on wildlife as a concern, noting that health and safety issues remain unknown and there is a lack of evidence to inform exposure guidelines for 5G (SCHEER, 2018). Some scientists have expressed concerns that children born today will experience cradle-to-grave lifespan exposure to RF EMR, in a context where health impacts remain poorly understood (Russell, 2018). A 2018 review found evidence that RF-EMF exposure drives biomedical effects in animals, increasing oxidative stress, a condition involved in cancer onset, as well as in several acute and chronic diseases and in vascular homeostasis (Di Ciaula, 2018). In follow up, a report of the Swedish Radiation Safety Authority found that the association between exposure to EMF and oxidative stress was not conclusive (Swedish Radiation Safety Authority, 2019). In terms of current exposure levels, a recent review found that RF-EMF exposure levels were highest in public settings, including libraries, train and tram stations, followed by outdoor and private indoor environments. Everyday RF-EMF exposure was not found to have increased since 2012, despite the increased use of wireless communication devices (Jalilian, et al., 2019).

Given the limitations in the current evidence base, coupled with the expected increase in exposure for the European population, further research regarding the possible long-term health effects of 5G deployment is important.

In relation to ELF fields, existing studies do not provide convincing evidence for a causal relationship between exposure and reported symptoms. A range of studies have found an increased risk of childhood leukaemia associated with exposure to ELF fields; however, no causal relationship can be identified, as no plausible mechanisms have been identified (EC, 2015c).

There are concerns that RF EMF may interact synergistically with other environmental stressors to affect health, with a recent study cautioning against possible systemic health effects (Kostoff, et al., 2020). The SCENIHR report also examined the potential impacts of co-exposure to EMFs and environmental stressors, with no definitive conclusions. The report recommends further research on the effects of co-exposure with other agents (EC, 2015c).

The WHO remains concerned about the potential health effects of EMF exposure, particularly regarding the knowledge gaps highlighted above. The WHO has an ongoing international EMF project assessing the health and environmental effects of electric and magnetic fields (WHO, 2018g).

4.9 Health impacts of multiple stressors

Key messages:

- People are exposed to multiple environmental stressors at any one time, combining — and in some cases acting synergistically — to have an impact on health. In particular, air pollution and high temperatures act synergistically, leading to increased morbidity and mortality.
- Social factors such as advanced age, poverty and pre-existing health conditions intensify the impacts of environmental health hazards on vulnerable groups, exacerbating health inequities.
- The urban population is particularly exposed to multiple stressors including air pollution, noise and chemicals while also having reduced access to green space. A high proportion of pregnant women and children in European cities were found to be exposed to air pollution and noise levels above health-based guidance values.
- The environmental burden of disease resulting from children's exposure to seven environmental stressors is estimated at 211 000 disability-adjusted life-years per year in children in the 28 Member States of the EU, with air pollution being the main contributor to this burden.
- Early efforts to map combined exposures to environmental and social stressors can identify areas at both the regional and the urban level that are vulnerable to the health impacts of environmental stressors.

Early work on environmental risks to health concentrated on single stressors in isolation. The reality is that people are exposed to multiple stressors at any one time and throughout their lives. In particular, the urban environment, where the majority of the European population resides, is characterised by the presence of multiple environmental hazards and reduced access to green spaces. It is the combined impact of these various stressors mediated by an individual's biological condition and social position that determine the health outcome for any one individual. As evidenced in the sections above, socially deprived urban neighbourhoods are often exposed to higher levels of noise and air pollution and often have a lack of green spaces.

There are currently two principal approaches to collating evidence to understand combined exposures. The first, known as the 'exposome', aims to capture all environmental exposures at the level of the individual, from conception to the end of their life, as a means of understanding environmental disease risk factors (Siroux et al., 2016). The second maps the spatial coincidence of multiple stressors by overlaying environmental monitoring data from different media, as well as social and demographic data. Both approaches cover not only environmental stressors but also social vulnerability.

This section reviews evidence of the combined impact of environmental and social stressors on health and summarises the results of efforts using these two approaches.

4.9.1 Cumulative and synergistic health impacts of multiple stressors

While evidence suggests that environmental stressors act synergistically on the human body to cause health outcomes, our understanding of the mechanisms involved remains limited.

The impact of a mixture of chemicals has come under particular scrutiny, with methods now emerging for combined risk assessment, as discussed in Section 4.6. Indoor air pollution can be made up of a mixture of pollutants that have additive effects, including carbonyls, VOCs, terpenes, PM and PAHs (WHO Europe, 2013b).

There is evidence of synergistic effects of exposure to air pollution (PM_{10} and ozone) and high temperatures leading to increased morbidity and mortality (Macintyre et al., 2018). In one study, air pollution exposure and heat exposure, together, explained about one third of the association between residential proximity to roads and low birth weight (Dadvand et al., 2014b). In relation to cold temperatures, the combination of PM_{10} and low temperatures increased morbidity for myocardial infarction in two provinces of Portugal (Vasconcelos et al., 2013). Allergen patterns are changing in response to climate change, with air pollution modifying the allergenic potential of pollens. While the underlying mechanisms are not understood, the health consequences include respiratory problems, allergic diseases, the exacerbation of chronic respiratory diseases and premature death (De Sario et al., 2013). There may also be an interaction between chemicals and climate change, in which temperature may increase pesticide toxicity (Hooper et al., 2012).

Air pollution and noise share some sources, such as road traffic and industrial activities, and their effects are difficult to disentangle. In cities, people exposed to air pollution tend to be also exposed to noise. The health effects of both types of stressors are similar and can therefore have a synergistic effect on human health (EEA, 2018a). The combined health impact of road traffic noise and air pollution across 497 European cities is estimated at an average of 1 745 DALYs per year per 100 000 inhabitants, corresponding to 6.2 % of the total burden of disease for all causes per year (ETC/ACM, 2018).

Social status can increase vulnerability to environmental stressors through increased exposure and sensitivity and reduced resilience. Individual vulnerability is determined by both internal and external factors, which are in turn influenced by socio-economic status. Underlying health conditions are internal factors, while external factors include exposure to environmental stressors as well as diet, exercise levels and smoking behaviour. For example, poor housing quality is linked to exposure to indoor antigens from mould, which increases the risk of respiratory symptoms, resulting in increased sensitivity to air pollutants (Solomon et al., 2016).

In terms of the mechanisms through which psychological stress resulting from social conditions combines synergistically with environmental stressors, one possible pathway is allostatic load. Allostasis refers to the body's ability to respond and adapt to transient stressors. Over time, stress and unhealthy behaviours can impair the body's ability to maintain allostasis, degrading bodily systems, compromising immune function and increasing susceptibility to environmental stressors (Clougherty et al., 2010). External factors, such as poor housing quality, as well as experiences, such as violence and racial discrimination, can increase allostatic load. External social conditions and internal biological susceptibility factors interact with environmental hazard inequalities to exacerbate health disparities (Morello-Frosch et al., 2011). For example, studies have found associations between violence and family stress and increases in the effects of traffic-related air pollution on childhood asthma (Clougherty et al., 2007; Shankardass et al., 2009).

4.9.2 Measuring exposure to multiple stressors

The exposome concept, depicted in Figure 4.19, describes the totality of human environmental exposures over a lifetime, in combination with gene expression (Vrijheid, 2014). The concept links conditions and diseases of late childhood and adulthood to early-life environmental conditions, to understand the role of environmental stressors in driving disease.

From 2012 to 2019, a cluster of exposome projects were funded under the European Commission's Horizon 2020 research programme, including HELIX ([20]), HEALS ([21]) and EXPOsOMICS ([22]).

HELIX focused on identifying patterns of combined exposure to chemical and physical stressors among pregnant women and children. A considerable proportion of pregnant women and children were found to be exposed to fine PM and traffic noise in dense city environments at levels above health-based guidelines, as well as to have insufficient contact with natural environments. In particular, chemicals were detected in the blood and urine of over 90 % of pregnant women and children. Apart from noise and PM, levels of the different environmental stressors were generally not related (HELIX, 2018).

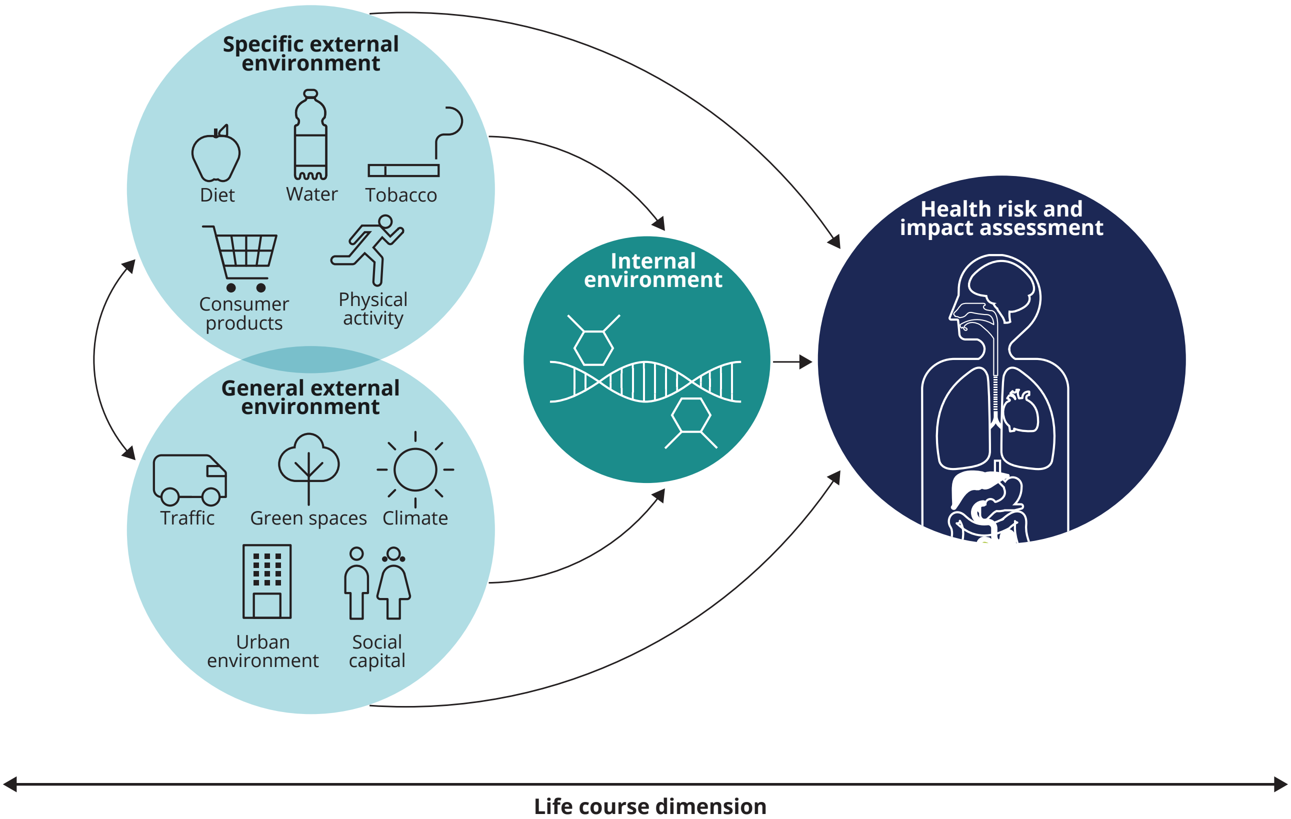
At the same time, exposure varied considerably across Europe for both chemicals and hazards related to city environments, confirming that location is a strong determinant of individual exposures. While in Bradford pregnant women of a low socio-economic position were exposed to higher levels of environmental hazards, in Oslo the opposite association was observed (Robinson et al., 2018).

The environmental burden of disease resulting from children's exposure to seven environmental stressors, including PM (PM_{10} and $PM_{2.5}$), ozone, second-hand smoke, dampness, lead and formaldehyde, was estimated at 211 000 DALYs per year in children in the EU-28 (Rojas-Rueda et al., 2019). The highest burden was attributable to air pollution, including PM and ozone.

HEALS developed a methodology for European-wide association studies of the environment and health, including the use of internal exposure data from human biomonitoring to de-code the exposome (Steckling et al., 2018). EXPOsOMICS focused on assessing exposure to air and water contaminants at both individual and population levels during critical periods of life using tools for personal exposure monitoring. Understanding external exposures is complemented by the use of omic technologies for the analysis of biological samples to identify

([20]) www.projecthelix.eu
([21]) www.heals-eu.eu
([22]) www.exposomics-project.eu

Figure 4.19 The exposome concept



Source: Based on Vrijheid (2014).

internal markers of exposures. The aim is to establish associations between external exposures and biological markers in the same individual (Vineis et al., 2017).

Looking forward, a new wave of exposome research is being funded under Horizon 2020. The aim is to produce more complete and more accurate individual-level exposure data to allow an estimation of the largely unknown environmental component of non-communicable diseases. The approach shifts away from 'one exposure, one disease' to a more complex picture of the environment, health and well-being nexus on which to build preventive actions and policies in the future.

4.9.3 Mapping the spatial coincidence of multiple stressors

An alternative approach to understanding multiple stressors is to overlay monitoring data from different environmental domains, as well as social data, to identify areas subject to multiple stressors.

Recent EEA work demonstrates how high social vulnerability spatially coincides with the occurrence of multiple types of hazard at European level. Map 4.10 presents, on the left side, the number of environmental health hazards for which a given NUTS 2 region is in the top 20 % in Europe in terms of exposure. The environmental health hazards considered include exposure to PM_{10}, NO_2, ozone, the number of cooling degree days and the number of heating degree days [23]. Regions in Italy suffer from all three types of air pollution as well as high temperatures. Regions where the population is substantially affected by three out of five hazards are located mainly in Greece, Italy and Spain. Of note, no regions in the north or north-west of Europe are substantially affected by more than two hazards.

The right-hand side of Map 4.10 shows the various dimensions of social vulnerability for which a given

(23) Cooling degree days is a measurement of the demand for the energy needed to cool a building to keep it at a comfortable temperature, while heating degree days measures the energy needed to heat a building.

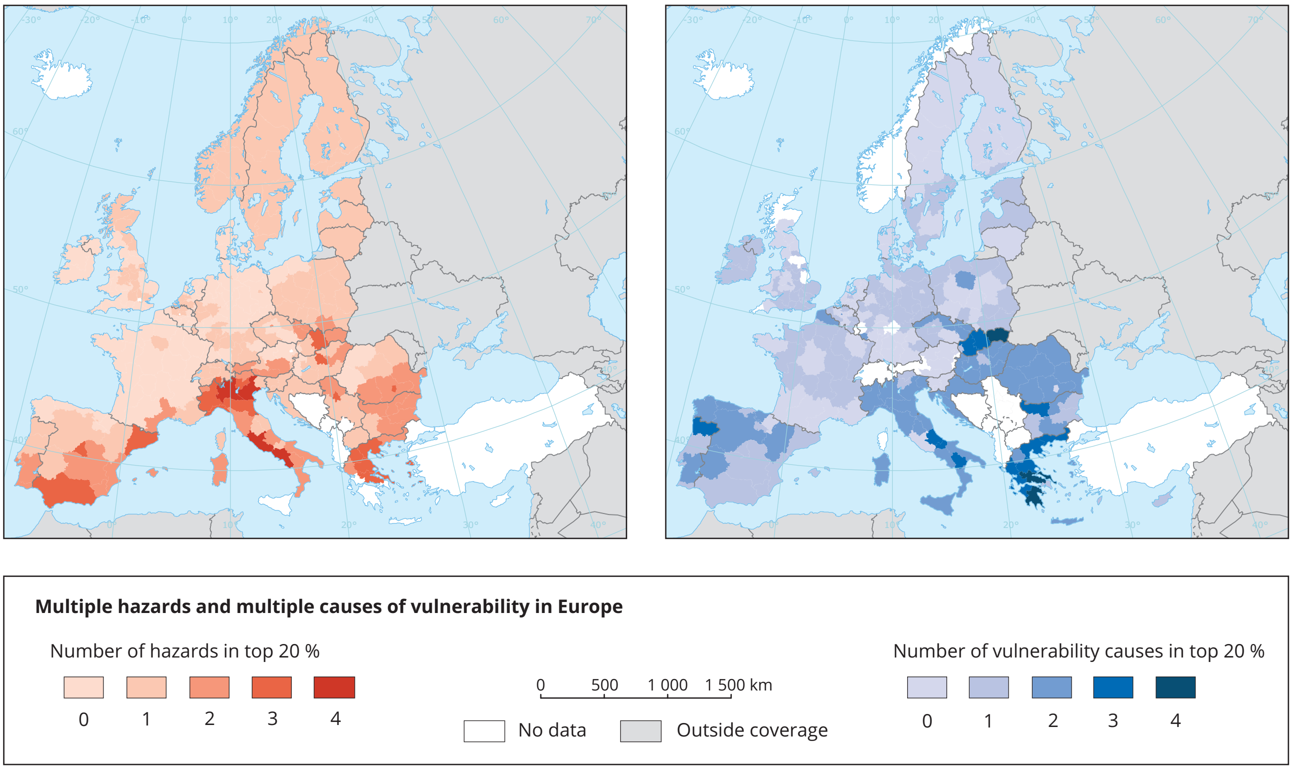
region falls in the top 20 % in Europe. The dimensions covered include the percentage of children under 5 years old among the population; the percentage of people aged 75 years or older among the population; the average household income; the percentage of long-term unemployed among the working-age population; and the percentage of people without higher education. There are some regions with four out of five causes of vulnerability in the top 20 %; low levels of income and education and high levels of unemployment overlap with high proportions of elderly people in Greece and with young children in Slovakia. The regions where high levels of three 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 high levels of vulnerability for more than two causes are present in the north and north-west of Europe.

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. A division can be seen between the south-east and the north-west of Europe, as the population in the south-east are both more exposed and more vulnerable to environmental hazards that have an impact on health. This shows that disparities in Europe are not only present in socio-economic terms (EC, 2017d) but also redrawn in relation to environmental justice.

The Federal State of Berlin took a similar approach at city level, producing a map that integrated environmental burden with social status (see Map 4.11), as described in Box 4.30.

Such efforts can help to identify areas that have a particular vulnerability to the health impacts of environmental stressors, enabling authorities to direct policy efforts to mitigate both environmental and social stressors. The challenge is to identify data sets for the same scale and time frame that can be meaningfully combined. Further efforts to map the spatial coincidence of exposures to environmental stressors and social deprivation on fine scales within cities are needed to better understand the dynamics at play in the urban setting and how they vary between cities.

Map 4.10 Multiple environmental hazards and multiple causes of vulnerability in Europe



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.

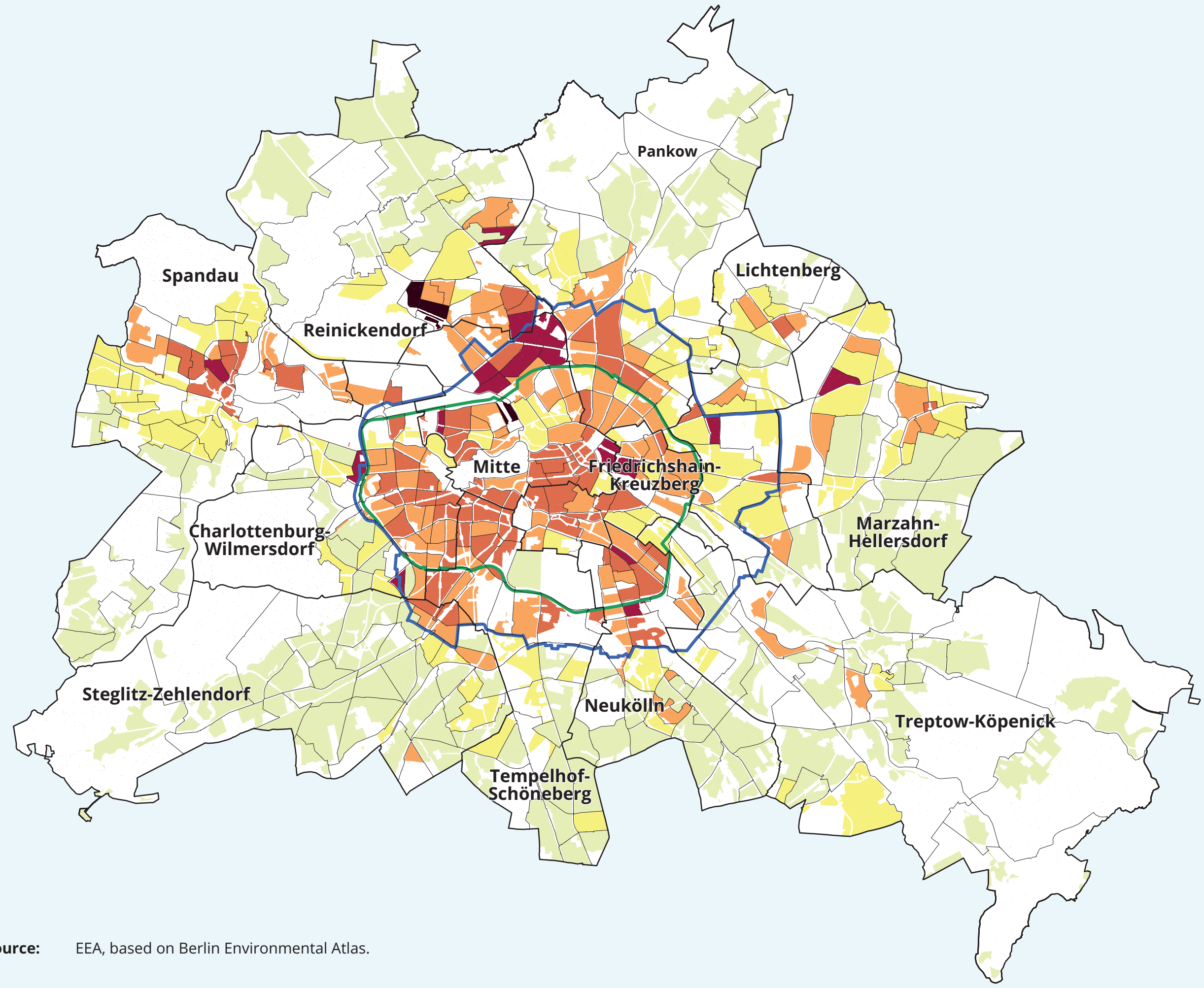
Source: EEA (2018a).

Box 4.30 Case study — Environmental Justice Initiative in Berlin

In 2010, the Federal State of Berlin initiated a project on environmental justice to examine the links between socio-economic status and health-related environmental conditions. The core objective of the citywide spatial analyses was to identify neighbourhoods with multiple burdens. The core indicators used as part of the assessment were noise, air pollution, green space provision, bio-climatic load and social status. Twelve additional indicators — e.g. premature mortality, morbidity, ecosystem services and urban structure — complete the indicator set. The analyses indicate that neighbourhoods with multiple environmental burdens tend to exhibit lower social status indicators.

The analyses of environmental justice form the basis for an interdepartmental and interdisciplinary monitoring system that is regularly updated. This 'early warning system' provides political decision-makers, urban and environmental planners and the scientific community with a sound basis for decision-making, to be able to tackle changing environmental conditions such as climate change. With this new approach, the Federal State of Berlin is taking on a pioneering role throughout Germany and Europe.

Map 4.11 Integrated environmental justice map of Berlin



Source: EEA, based on Berlin Environmental Atlas.

Integrated environmental justice map of Berlin

Integrated environmental load with social status

- Five times burdened
- Four times burdened
- Triple burdened
- Double burdened
- Single burdened
- No burden
- No settlement area

Multiple burdens

- High ambient air pollution
- High noise load
- High bioclimatic burden
- Low green space provision
- Low social status

Focus area inner city (Priority area for air purity according to land use plan)

Border of environmental zone

Source: Berlin Senate Department for Environment, Transport and Climate Protection, Berlin (2019).

5 Final reflections

5.1 The environmental burden of disease in Europe

Today, the environment is recognised as a core dimension of quality of life. Researchers and policymakers are paying increasing attention to the dynamic linkages between the health of populations, their material living conditions and the environment in which they live, work and play. In recognition of this, the European Commission has introduced a 'zero pollution' ambition to protect citizens' health from the adverse impacts of environmental pollution, including air pollution, water pollution, noise and chemicals. This provides an impetus for countries to continue and substantially strengthen activities in these areas to address the current impacts that pollution continues to have on the health and quality of life of European citizens.

A body of EU legislation is in place to provide Europeans with an environment that can support their quality of life and provide essential ecosystem services such as drinking water, clean air and safe food, as well as sufficient and suitable space for recreation and relaxation. Policies to reduce exposure to environmental risks have delivered substantial gains in terms of improved environmental quality and benefits for health. For example, the quality of drinking water in Europe is generally very good and directly supports health. Efforts are also ongoing to modernise drinking water quality standards, with new controls proposed for emerging chemicals. Policies to improve bathing waters have also been successful, with the majority of Europeans enjoying good recreational bathing conditions.

Improvements in air quality, driven by the measure to limit air pollutant emissions, have delivered significant reductions in health impacts in Europe, from around 1 million premature deaths attributable to particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$) in 1990 to 417 000 in 2018. Further reducing $PM_{2.5}$ concentrations will continue to bring about health benefits and reductions in the number of premature deaths.

Progress has not been as positive for all environmental risk factors. For example, the impacts of environmental noise remain a significant and often underestimated burden on the quality of life and health of European citizens. Similarly, the risks presented by poor indoor air quality merit further attention. The impacts of climate change on health are predicted to increase significantly and will exacerbate the impacts of other environmental risk factors, in particular air pollution.

While evidence from human biomonitoring studies carried out across Europe suggests that all people have exogenous chemicals in their bodies, the understanding of the impacts of chemicals on human health in Europe is patchy. Nevertheless, approaches to regulating groups of chemicals and integrating the principle of safe by design into production processes offer ways of tackling chemical risks. Regarding electromagnetic fields (EMFs), both the potential for long-term health effects and current levels of human exposure are not well understood in Europe.

Notwithstanding the achievements in addressing some environmental risk factors, the environmental burden of disease in Europe remains a significant contributor to the total burden of disease, with one in eight deaths driven by environmental pollution. There is still substantial scope for further improvements, both in terms of reducing the magnitude of the environmental burden of disease and addressing geographical and social inequity in the distribution of this burden.

5.2 The social dimension

This report provides evidence of the unequal impact of environmental pollution and degradation on socially deprived communities and vulnerable groups. While policies to improve environmental quality are in most cases delivering positive outcomes for the general population, vulnerable groups are being left behind.

For example, the health impacts associated with air pollution are unevenly distributed across Europe, with exposure to $PM_{2.5}$ shortening lives in eastern and southern Europe and exposure to nitrogen dioxide (NO_2) shortening lives in the west of Europe. In addition, a growing body of evidence indicates that health impacts of air pollution are unevenly distributed across social groups. Children, pregnant women and the elderly are more sensitive to the health impacts of various air pollutants, with the impacts on children's cognitive development having lifelong implications. In terms of exposure, studies have found that deprived urban communities face higher levels of air pollution than wealthier urban areas, leading to an increased health burden that may be exacerbated by pre-existing health conditions, with a higher prevalence in poorer communities.

While chemicals are regulated under a comprehensive range of policies, there is no overarching approach that addresses the reality of everyday exposure to the many and complex mixtures of chemicals. Individual chemical exposure is influenced by personal behaviours, diet and consumer choices, some of which are mediated by social status. Understanding the drivers behind exposure to specific chemicals can inform measures to minimising exposures, in particular for vulnerable groups such as pregnant women and children.

Policies to deliver high environmental quality should be aimed at preventing and reducing the unequal distribution of environmental health risks, ensuring fair access to environmental resources and enabling sustainable choices. A first step would be to integrate these goals into environmental legislation, such as the agendas for climate change and air pollution. Universal measures to deliver overall reductions in exposure for the general population can be complemented by measures targeted at groups known to be vulnerable in terms of their increased exposure, increased sensitivity or reduced resilience.

A second step would be to integrate the concept of environmental inequity into other policy domains. At European level, options exist to explicitly target socio-environmental inequalities through the EU Cohesion Fund and the European Social Fund, since environmental inequalities follow the pattern of socio-demographic inequalities across Europe. This could be achieved through funding to improve environmental quality in disadvantaged urban neighbourhoods and to enable people to make more sustainable choices, for example by subsidising clean fuels. At the local level, integrating environmental health concerns into welfare policies, health policies and urban planning can help to reduce the vulnerability and exposure of the population. The World Health Organization Regional Office for Europe has produced guidance on how to monitor, assess and manage environmental health inequalities (WHO Europe, 2019d). An example of action to understand and tackle environmental justice in Germany is provided in Box 5.1, together with emerging recommendations for local authorities.

5.3 Integrated policies for the environment, health and well-being

Historically, policies to control environmental risks to health focused narrowly on single stressors, for example those aiming to reduce population level exposure to air pollution. In reality, multiple stressors act together to lead to a deterioration in quality of life, in combination with social deprivation and demographic factors.

The systemic links between community health, social context and the local environment offer opportunities for synergies when designing interventions to improve quality of life across these dimensions. This requires integrated policy approaches that take into account dimensions of environmental quality as well as social factors such as economic circumstances, behaviours and demographics. In particular, understanding behaviours and the underlying mechanisms across different groups is important in designing measures that can support and enable people to make sustained positive changes, such as dietary shifts, increased exercise and reduced car use. In some cases, changes may be inhibited by poverty, such as switching from solid fuel use for residential heating to cleaner fuels and consuming more vegetables. Targeted subsidies coupled with education/awareness raising can support behavioural changes that benefit both the environment and health, particularly among poorer communities (Inherit, 2019b).

Environmental health issues can also be addressed through health policies. The health-in-all-policies approach tackles the environmental, economic and social determinants of health. Given the benefits of social expenditure on prevention in reducing health inequalities, it is significant that only 3 % of the EU health budgets are spent on prevention (Eurostat, 2019a). A specific objective of the EU's third health programme (2014-2020), 'Funding Health Initiatives', is promoting health, preventing disease and fostering supportive environments for healthy lifestyles (EU, 2014). Integrating environmental quality objectives into preventive health policies offers opportunities to reduce disease and promote well-being. An example of cross-agency collaboration to deliver environmental health in Sweden is presented in Box 5.2.

High-quality natural environments offer significant benefits for local communities in terms of healthier living, both physically and mentally. In particular, ever-increasing urbanisation combines dense populations, often with high proportions of elderly people, with exposure to multiple environmental stressors, including air pollution, noise and heat. Failure to address the environmental risk factors associated with urbanisation will have significant implications for future generations.

Box 5.1 Research and action on environmental justice in Germany

The German Environment Agency has worked extensively on the uneven distribution of environmental resources and exposure to environmental pressures and the implications for health. Funded by the German Environment Agency, from 2012 to 2014 the German Institute of Urban Affairs (Difu) carried out the research project 'Environmental justice in urban areas — development of feasible strategies and measures to reduce socially unequally distributed health-related environmental burden'. This explored how local authorities can be supported in their activities to create environmental justice at a local level. The following recommendations for municipalities were developed (Böhme et al., 2015).

Integrated governance: the study shows that coordinated action by all relevant departments and stakeholders is indispensable. This requires, in particular, a greater socio-spatial orientation of the local environment and health departments.

Integrated monitoring: a two-stage procedure was proposed, consisting of a citywide analysis and a more in-depth investigation of areas identified as being subject to multiple burdens in the first step. The approach requires the combined use of environmental, health and social data. A selection of basic and more detailed indicators is provided for orientation.

Formulation of objectives and measures: it is essential to determine the area-related need for action. Links — e.g. for inclusion in integrated urban development concepts — should be identified.

Use of planning instruments and instruments in environmental law: a set of instruments appropriate to the planning area concerned must be applied. In environmental planning, for example, a systematic check for socio-spatially oriented priorities would be beneficial.

Use of financial resources: funding from support programmes should be targeted at areas with multiple burdens. The performance of pilot projects would make it possible to test the practicality of the approaches developed in the project.

Participation and involvement of those affected: appropriate citizen participation in the planning and decision-making processes is important. This should include methods that engage socially disadvantaged people.

The first research project was followed up with a pilot project in German municipalities, run by Difu from 2015 to 2019 and funded by the German Environment Agency. It aimed to prevent and reduce the unequal distribution of environmental health risks. The pilot project tested the recommendations outlined above in three pilot municipalities: Kassel, Marburg and Munich. The project identified measures suitable for promoting environmental justice and how they might be integrated into ongoing activities at municipal level and mainstreamed politically. It also considered how to identify urban areas exposed to multiple burdens. The assessment found different opportunities for promoting environmental justice in individual towns and cities. Success factors included scrutinising strategies linked to environmental justice, securing backing from local politicians, identifying an 'advocate' in the administration to lead the issue and ensuring cooperation across different departmental bodies at the strategic and working levels (Böhme et al., 2019).

Against the background of the project's findings, the online toolbox 'Environmental Justice' (www.toolbox-umweltgerechtigkeit.de) was created to support municipalities, including providing definitions, background information, checklists, advice on implementation and practical examples.

Box 5.2 Delivering environmental health through collaboration in Sweden

Cross-sectoral collaboration on environmental health in Sweden
In 2017, the Swedish Public Health Agency initiated a collaboration involving 13 national and two regional agencies in the project 'Health as a driving force for the environmental objectives and for sustainable development'. The project was set up under the Environmental Objectives Council, a body that includes representation from 18 national agencies involved in delivering Sweden's environmental objectives. These agencies work with a wide array of sectors, including transport, forestry, agriculture, public health, marine, energy, housing and planning, food, chemistry, geology, radiation and environment.

Collaboration across national bodies enabled access to a richer knowledge base and a broader set of perspectives, providing a better basis for decision-making. It also informed efforts to influence decisions in the international arena through cross-sectoral messages. Local and regional actors were able to identify and harness synergies across policy domains for environment and health.

Opportunities to strengthening environmental health in Sweden
The project identified opportunities to work more efficiently on environmental health in Sweden. The strength of the outcome resulted from the unified voice of the many sectors involved, recognizing and harnessing the diversity of perspectives and knowledge. The project identified opportunities to:

- Emphasize health as a driving force across policies and a common goal;
- Raise the profile of health aspects that represent common priorities for several sectors and actors;
- Highlight the benefits associated with the environment, and not only environmental risks;
- Consider equity issues when planning actions on environmental health;
- Strengthen collaboration in environmental health.

Establishing a national network to strengthen environmental health
The success of the collaboration was primarily due to the mandate given by the Environmental Objectives Council. This raised the issue of health as a driving force for environmental work at the agencies involved, and ensured that resources were set aside for collaboration. In follow up, Sweden is establishing a national network for environmental health, including the government agencies involved in the project and other relevant actors, to be coordinated by Sweden's Public Health Agency.

Proposed joint actions
Joint actions proposed for the network to implement include:

- A national portfolio of actions on environmental health in accordance with the Ostrava Declaration (WHO Europe, 2017a);
- Analyses of the socio-economic dimension in environmental health, in order to prioritize resource allocation;
- A coordinated national study of environmental health;
- The development of indicators to measure health equity;
- The use of foresight tools to understand future environmental health;
- Mapping international processes on environmental health where Swedish agencies participate.

Source: Private communication from the Public Health Agency of Sweden.

5.4 A triple win for the environment, health and society

Understanding how social status mediates the environment, health and well-being nexus through both positive and negative pathways present an opportunity to pursue joint solutions. Investing in nature offers a triple win, yielding benefits for the environment, health and society (Inherit, 2019b).

Green infrastructure in urban areas mitigates stressors such as noise, extreme heat and to a lesser extent air pollution, increases resilience to climate-related floods and promotes urban biodiversity. In addition, green spaces in urban areas providing public space for relaxation and exercise facilitate community interactions and so reduce social isolation, a risk factor for adverse health outcomes. Deprived communities derive particular benefit from nature in terms of mental health, as well as reductions in mortality and morbidity, implying that green and blue spaces can be a tool in tackling pervasive health inequities. Migrant and marginalised communities find opportunities to integrate with local communities in parks and urban green spaces, fostering a sense of belonging. As a result, urban green space offers municipalities a tool for delivering a triple win, offering benefits to health, society and the environment.

An integrated approach also highlights opportunities to tackle multiple stressors with common sources. For example, clean and smart transport solutions in urban areas can deliver benefits in terms of cleaner air, less noise and reduced greenhouse gas emissions. In addition, reduced congestion combined with improved infrastructure for walking and cycling encourages physical activity. Providing mobility options for the 'first mile' and 'last mile' of journeys taken by public transport increases the connectivity of urban transport solutions, making active and sustainable transport modes more attractive (EEA, 2020c). In a context in which approximately two thirds of people in the EU fail to achieve the World Health Organization (WHO) recommendations for physical activity (Eurostat, 2018c) — as sedentary lifestyles are a key driver of non-communicable diseases — promoting exercise is a public health priority.

Another example relates to the food system, critical to human nutrition, as well as livelihoods and culture. Unsustainable agriculture leads to the pollution of soil, water, air and food, degrades ecosystems and drives biodiversity loss, with knock-on effects on human health. For example, ammonia emissions from agriculture, in particular animal manure, contribute to the formation of PM in ambient air, while pesticide use reduces pollinator populations and leaves residues in foods. At the same time, an unhealthy diet that is high in animal protein, sugar and fats, combined with low levels of exercise, leads to people becoming overweight or obese, increasing the risk of cardiovascular diseases, certain types of cancer, hypertension and type 2 diabetes. Meat and dairy products contribute around 25 % of the environmental impacts caused by total final consumption of products in the EU, with livestock being more than six times less efficient than crops in producing protein. Dietary shifts towards consuming lower quantities of meat, dairy products and eggs would reduce environmental impacts as well as reduce health risks. At the same time, ensuring that the food system contributes positively to social well-being in Europe means providing viable and just livelihoods for farmers, fishers and other workers involved in the food system (EEA, 2017c).

5.5 Systemic challenges and trade-offs across policy domains

Persistent environmental pollution and degradation results from environmental pressures, such as greenhouse gas emissions, industrial air and water emissions, waste generation and land clearance. These pressures are driven by our economic activities and lifestyle demands, in particular the societal systems that provide our energy, food and mobility. The systemic character of Europe's environmental challenges explains why policies designed to address environmental stressors in isolation have only been partly successful. Environmental impacts remain high and current trends are not on track to achieve long-term environmental and sustainability goals (EEA, 2019a).

Shifting the policy focus towards sustainability, to deliver positive outcomes for the environment, health and society, requires common goals across policy areas. It requires an awareness of the need for trade-offs across policy domains when priorities conflict, presenting challenges to developing integrated solutions.

For example, climate change objectives can conflict with efforts to reduce air pollution. Insulating buildings to reduce energy loss can limit ventilation, leading to poor indoor air quality if the buildings are not properly designed. Measures that incentivise the use of biomass for home heating can negatively have an impact on indoor and outdoor air quality and damage health.

Current efforts to shift towards a circular economy offer the potential to reduce the impacts of our production and consumption systems, with potential benefits for health. However, there is a need to consider the potential impacts on health and well-being when developing and implementing circularity, to avoid negative outcomes. For example, in promoting recycling, there is a need to ensure that hazardous chemicals are not channelled into, and in some cases magnified in, secondary products, leading to human exposure. Impact assessments provide a means for integrating health concerns when considering circularity options, with a range of health-related assessment methods available (WHO Europe, 2019c).

In terms of priorities in the health sector, pharmaceuticals are used extensively to treat disease, support recovery and maintain good health. At the same time, releasing pharmaceuticals into the environment via waste water treatment plants has an impact on ecosystems. In the case of antibiotics, releasing them into the environment drives the development of bacteria, viruses and some parasites that are resistant to antimicrobial drugs. In turn, antimicrobial resistance presents a major threat to the effective prevention and treatment of a range of infections and is a serious threat to public health.

More broadly, economic growth is the principal driver of poverty alleviation. Yet, the current pattern of economic growth is driven by unsustainable consumption and production — the root cause of environmental degradation.

The COVID-19 pandemic presented society with a trade-off between protecting health and maintaining economic growth. The immediacy of the threat resulted in rapid action to protect health in many countries and regions. The threats that environmental degradation and climate change pose to human health are no less profound but the impacts manifest over longer timescales through complex dynamics. Addressing these risks requires systemic change through visionary policies implemented over the long term and supported by transparent and science-based public discourse.

5.6 Research needs in the environment, health and well-being nexus

There is sufficient evidence available to support policy actions to improve the environment, health and well-being. A lack of knowledge should not be used to justify inaction.

Environmental health practitioners should avoid getting lost in complexity when looking for clear directions for action. It is unlikely that we will ever be able to map all the complex, cumulative exposures of the European population, untangle the influence of social dimensions and establish causal links to health outcomes. Clear opportunities to address individual environmental risk factors should be taken without delay, while also taking into consideration their potential impact on other stressors and, where possible, adjusting existing policy measures to address multiple stressors through innovative and integrated approaches. The precautionary principle provides a basis for action, to protect health and the environment on the basis of early evidence of harm.

At the same time, there are specific environmental risk factors and emerging issues of concern that warrant further attention from researchers. In particular, the environment and health community would benefit from greater clarity regarding the linkages between the environment, social and health dimensions, including the influence of social status, behaviours and consumer choices.

Research designed to deliver societal benefits should investigate and disseminate social and technological innovations that can support improvements in environmental health.

The research needed to address current knowledge gaps is outlined in Box 5.3.

Box 5.3 Research needs in the field of the environment, health and well-being

Knowledge gaps regarding environmental impacts on health

- Further analysis is required on a European scale to understand regional differences in environmental quality and the drivers that lie behind those differences.
- Regarding air pollution, the quality of indoor air across Europe is poorly understood and would benefit from further research. A particular focus could be on the school environment.
- Current approaches to estimating the health impacts of air pollution operate at population level and focus on premature mortality. It would be useful to understand the health impacts of air pollution in local areas, capturing both mortality and morbidity effects. The latter could be linked to hospitalisation rates during peaks in air pollution.
- Further knowledge is needed to understand exposure to multiple stressors in urban areas, their relative importance and resulting health impacts. This could include efforts to map multiple exposures across different scales, as well as methods to measure the individual exposures described above. For example, there is a need for an enhanced understanding of how air pollution and noise combine to affect health. Another area with open questions is the role that climate change plays in exacerbating other environmental stressors, such as air pollution and the risks posed by chemical stressors.
- The potential for long-term health impacts of and exposure to electromagnetic fields remain poorly understood.
- Further work is needed to understand the prevalence of microplastics in the environment and the potential impacts on food, drinking water and health.
- Regarding chemicals, the HBM4EU ([a]) project is expected to yield the first European data set on human exposure to chemicals. Further work should investigate trends in exposure over time, to evaluate policy measures to reduce exposure. Non-targeted screening is essential for identifying known, emerging and unknown contaminants in the human population, as well as in environmental media.
- The impacts of agro-chemicals, including pesticides and fertilisers, on ecosystem services such as pollination and the provision of clean drinking water are poorly understood.

Research needs on the environmental health dimensions of COVID-19

- There is a need to better understand the role that environmental degradation plays in driving the emergence of zoonotic disease, including deforestation and habitat fragmentation, for example through increased surveillance of zoonotic disease across different habitats. Research should also explore the upstream drivers of habitat degradation, including intensive agriculture, mining and urban development.
- Research should focus on how human-animal interactions in the food system, in particular in intensive meat production, can led to the emergence of zoonotic disease.
- Further research is needed to explore the role that air pollution may play in influencing the transmission and severity of COVID-19. This includes an assessment of how long-term exposure to key pollutants may have influenced the COVID-19 death rate, based on comparable data, where possible. Research should seek to elucidate the mechanisms through which long-term exposure may weaken the immune defenses of the lungs and increase susceptibility to respiratory infection.
- The potential association between social deprivation and vulnerability to COVID-19, and in particular the role of higher levels of exposure to air pollution in poorer communities, requires further research.
- The question of whether PM can act as a carrier for the SARS-CoV-2 virus should be explored.

Knowledge gaps regarding the social dimension

- There is a need to better understand the role that social status plays in determining exposure to environmental risks, and in influencing sensitivity and resilience.
- Further investigation is needed into how access to green and blue spaces is developing and changing across Europe and into the key national drivers of these changes.

Box 5.3 Research needs in the field of the environment, health and well-being (cont.)

- A better understanding of the role that housing quality plays in increasing exposure to environmental stressors, including noise, indoor air pollution and chemicals, is needed.
- It will be important to explore how shifting demographics in Europe may lead to a greater vulnerability to environmental stressors, through increased sensitivity and reduced resilience.
- The Copernicus Urban Atlas data can be used to assess the spatial distributions of populations and green areas in urban areas across Europe. There are opportunities to assess how socio-economic status might affect access to green space in urban areas and high-quality environments outside cities, such as national parks, by mapping data provided under the Copernicus Land Monitoring Service against available socio-economic data on different scales.

Solution-oriented research

- It will be important to report on and share case studies that provide concrete evidence of how nature-based solutions can deliver a triple win at local, national and European scales.
- Research could usefully test and recommend innovative measures to manage the impact of climate change. This may include looking into the role of green infrastructure in adapting to predicted changes to the hydrogeological cycle that are expected to impact on surface water, drinking water and bathing water quality.
- Evidence of the health and social benefits of green and blue spaces and recommendations for how to foster behaviours to increase the use of green and blue spaces should be gathered.
- A better understanding of how the human microbiome is influenced after time spent in natural environments and the subsequent benefits for the immune system is needed.
- It is important to report on best practice in implementing policies that integrate environmental, health and social concerns in the urban context, including the governance approaches needed to build consensus across policy domains and drive implementation.

Methodological approaches

- Undertaking analyses of different types of data — including information on social and demographic status, health and environmental quality — can help to identify linkages across these domains on European, national and local scales. The challenge is to identify data sets that cover the same scale and time frame and so can be meaningfully combined.
- Combining data on environmental quality with health data on various spatial scales could yield valuable insights regarding associations between exposure and health outcomes.
- Innovative tools and methods are being deployed to measure environmental exposures at an individual level, which can be combined with data on socio-economic status and behaviour. The exposome provides a tool for mapping exposures along the lifecycle and teasing out links with social status and behaviours. This has the potential to yield large data sets that are valuable for exploring the drivers of single and multiple exposures and the impacts on health.
- Cohort studies are well suited to exploring the role that exposure to environmental risks and access to environmental benefits play as a health determinant along the lifespan of an individual.
- Citizen science, whereby the public contributes to data gathering, offers new opportunities for monitoring local environments. Data generated by citizen science can pose challenges in terms of robustness and spatial coverage; further reflection on how they might be best combined with the results of coordinated monitoring activities is required. Such an initiative fosters public engagement with environmental issues, with impacts on local social and environmental conditions being worthy of exploration.

Note: ([a]) HBM4EU is a European human biomonitoring initiative under the Horizon 2020 project: www.HBM4EU.eu.

Abbreviations

7th EAP	Seventh Environment Action Programme
ADHA	Attention deficit hyperactivity disorder
AIDs	Acquired immune deficiency syndrome
AMR	Antimicrobial resistance
ANSES	French Agency for Food, Environmental and Occupational Health and Safety
ARPAV	Regional Agency for Environmental Protection and Prevention
BAME	Black, Asian and minority ethnic
BaP	Benzo[a]pyrene
BBzP	Benzyl butyl phthalate
BPA	Bisphenol A
CLP	Classification, Labelling and Packaging
COVID-19	Coronavirus disease 2019
DALY	Disability-adjusted life-year
DCHP	Dicyclohexyl phthalate
DEHP	Di-2-ethyhexyl phthalate
DiBP	Diisobutyl phthalate
Difu	German Institute of Urban Affairs
DnBP	Dibutyl phthalate
ECHA	European Chemicals Agency
eDPSEEA	Ecosystems-enriched drivers, pressures, state, exposure, effect, actions (model)
EEA	European Environment Agency
EEA-33	33 EEA member countries
EEA-39	33 EEA member countries plus six collaborating countries (Albania, Bosnia and Herzegovina, North Macedonia, Serbia and Kosovo (under UN Security Council Resolution 1244/99)

EFSA	European Food Safety Authority
Eionet	European Environment Information and Observation Network
ELF	Extremely low frequency
EMF	Electromagnetic field
ETC/WMGE	European Topic Centre on Waste and Materials in a Green Economy
EU	European Union
EU-28	28 Member States of the EU
GDP	Gross domestic product
HEAT	Health economic assessment tool
Helcom	Baltic Marine Environment Protection Commission
HIV	Human immunodeficiency virus
IPCC	Intergovernmental Panel on Climate Change
JAHEE	Joint Action Health Equity Europe
JRC	Joint Research Centre of the European Commission
MEHP	Mono-2-ethylhexyl phthalate
MERS-CoV	Middle East respiratory syndrome coronavirus
MiBP	Monoisobutyl phthalate
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxide
NUTS	Nomenclature of Territorial Units for Statistics
PAH	Polycyclic aromatic hydrocarbon
PBDE	Polybrominated diphenyl ether
PCB	Polychlorinated biphenyl
PFAS	Per- and polyfluorinated alkyl substance
PM	Particulate matter
$PM_{2.5}$	Particulate matter with a diameter of 2.5 μm or less
PM_{10}	Particulate matter with a diameter of 10 μm or less
ppb	Parts per billion
PPS	Purchasing power standard

PVC	Polyvinyl chloride
QALY	Quality-adjusted life-year
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RCP	Representative concentration pathway
RF	Radio frequency
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SDG	Sustainable Development Goal
UN	United Nations
UNECE	United Nations Economic Committee for Europe
Unesco	United Nations Educational, Scientific and Cultural Organization
VOC	Volatile organic compound
VTEC	Verocytotoxigenic *E. coli*
WASH	Water, sanitation and hygiene
WHO	World Health Organization
YLL	Years of life lost

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